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SECTION OF GEOLOGICAL SCIENCES

ZINC AND LEAD DEPOSITS OF SHAWANGUNK MOUNTAINS, NEW YORK*

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Introduction

The Shawangunk zinc-lead district consists of five mines or major prospects on Shawangunk Mountain between Port Jervis and Ellenville in southeastern New York. A sixth occurrence was found in the construction of the Delaware Aqueduct Tunnel near Napanoch, N. Y. Mining in the area dates back to about 1820 (Mather, 1843, p. 358) but the occurrences of ore were of very minor economic importance. The largest reserves are at Wurtsboro, where about 100,000 tons of zinc-lead ore were indicated by United States Bureau of Mines drilling in 1947 and 1948.

The deposits are of scientific interest, however, as representatives of the "Appalachian type" of lead-zinc deposit occurring in somewhat unusual geologic surroundings. An examination of these surroundings, compared with the more usual setting of lead-zinc deposits may not solve any of the perplexing problems of origin, but may contribute some pertinent data.

The principal characteristics of Appalachian lead-zinc deposits are: (1) occurrence in sedimentary rocks, usually carbonates; (2) simple mineralogy, including sphalerite, galena, one or two gangue minerals, plus usually some pyrite and, occasionally, chalcopyrite; (3) ore emplacement by fissure and breccia filling and replacement; (4) the absence of any obvious source of hydrothermal solutions, such as igneous intrusions; and (5) structural and stratigraphic control, which are important guides to ore.

The Shawangunk Mountain deposits fit into this general scheme, with one major difference; the host rock is quartzite rather than carbonate.

Shawangunk Mountain, between Port Jervis and Ellenville, is a nearly straight, homoclinal ridge supported by resistant quartzites and conglomerate of Silurian age. The mineralized areas are all on the northwest side of the ridge, as indicated in FIGURE 1. The deposits having had the most significant production are at Guymard, Wurtsboro, and Ellenville. Extensive prospecting and, possibly, some production was carried out at Otisville and Spring Glen.

*This paper, illustrated with slides, was presented at a meeting of the Section on December 5, 1960. This article, a condensation of a Ph. D. dissertation (Gray, 1947 and Gray, 1953) prepared at Columbia University, New York, N. Y. under the direction of C. H. Behre, Jr., was made possible by a grant from the New York State Museum, Albany, N. Y.

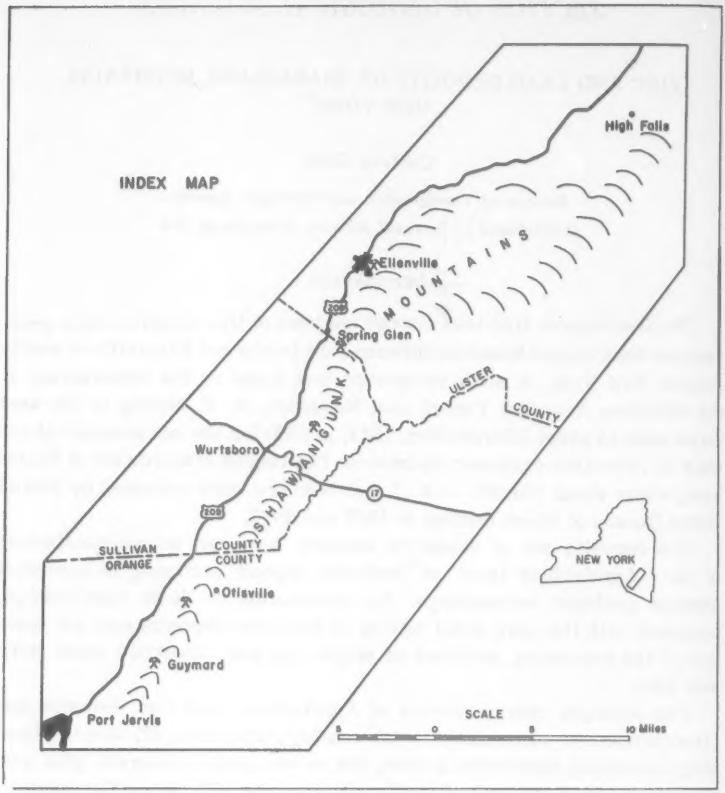


FIGURE 1.

Stratigraphy

The principal rock unit on Shawangunk Mountains is the Shawangunk Formation, a complex of conglomerate, cross-bedded coarse sandstone and quartzite with some thin shale interbeds. FIGURE 2 shows a columnar section of the formation at Ellenville. The Shawangunk Formation unconformably overlies the Ordovician "Hudson River" shales. The thickness of the unit increases from 550 feet at Ellenville to more than 900 feet at Guymard (FIGURE 3).

Overlying the Shawangunk Formation from Ellenville to the area of Otisville is the High Falls Formation, consisting of brownish-red and green-silty shale and fine sandstone. Disseminated pyrite is characteristic of this unit. The High Falls Formation is about 100 feet thick at Ellenville, increases to about 170 feet at Wurtsboro, and then decreases to 14 feet at Otisville. It has not been identified southwest of Otisville.

From Wurtsboro to Ellenville, the High Falls is overlain by Binnewater Sandstone, a white-to gray-quartzitic sandstone, generally fine- to medium-grained, but locally contains beds of pebble conglomerate. Red sandstone beds are present in the upper part of the formation at Wurtsboro.

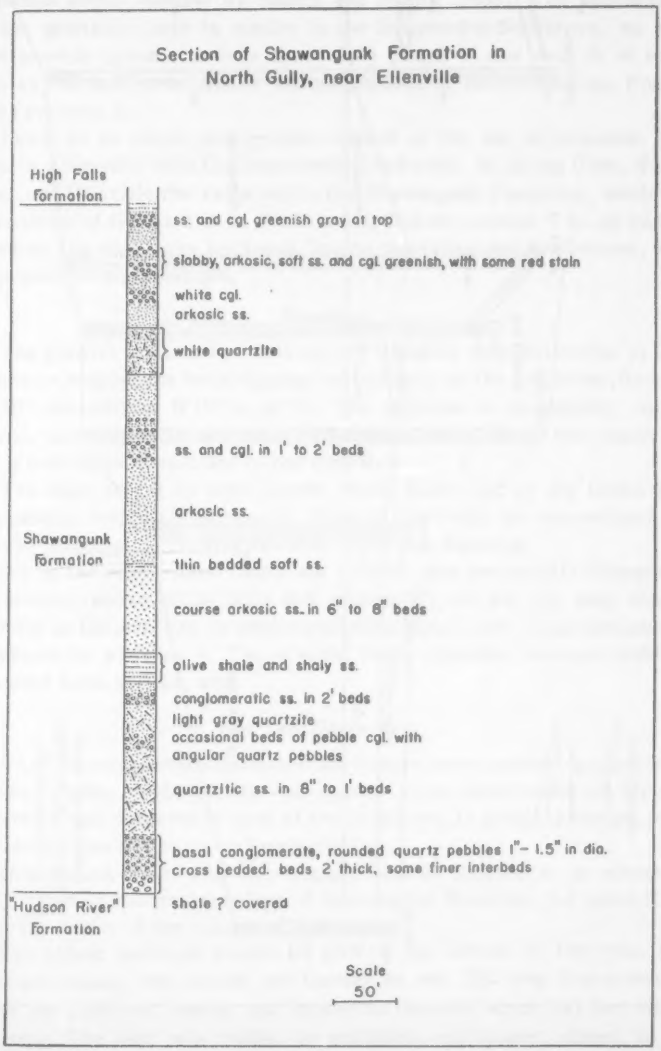

Section of Shawangunk Formation in North Gully, near Ellenville
High Falls Formation
ss. and cgl. greenish gray at top
slobby, arkosic, soft ss. and cgl. greenish, with some red stain
white cgl.
arkosic ss.
white quartzite
ss. and cgl. in 1' to 2' beds
arkosic ss.
Shawangunk Formation
thin bedded soft ss.
course arkosic ss. in 6" to 8" beds
olive shale and shaly ss.
conglomeratic ss. in 2' beds
light gray quartzite
occasional beds of pebble cgl. with
angular quartz pebbles
quartzitic ss. in 8" to 1' beds
basal conglomerate, rounded quartz pebbles 1"– 1.5" in dia.
cross bedded. beds 2' thick, some finer interbeds
"Hudson River" Formation
shale ? covered
Scale
50'

FIGURE 2.

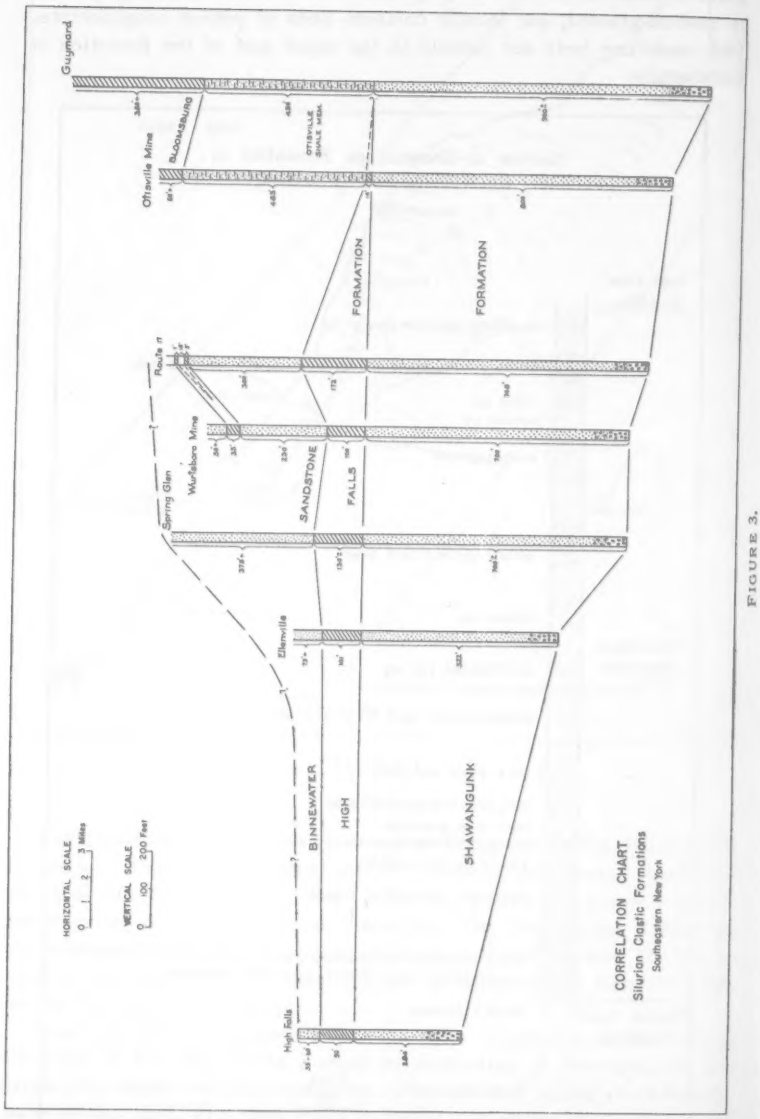

Guymard
Otisville Mine
BLOOMSBURG
OTISVILLE SHALE MBR.
FORMATION
FORMATION
Route 17
Wurtsboro Mine
Spring Glen
SANDSTONE
FALLS
Ellenville
BINNEWATER
HIGH
SHAWANGUNK
High Falls
HORIZONTAL SCALE
0 1 2 3 Miles
VERTICAL SCALE
0 100 200 Feet
CORRELATION CHART
Silurian Clastic Formations
Southeastern New York

FIGURE 3.

From Ellenville to south of Wurtsboro the Binnewater Sandstone forms the lower slopes of the ridge and younger beds are covered by Pleistocene outwash and till.

At Otisville, the High Falls Formation is overlain by more than 400 feet of gray quartzitic sandstone and greenish-gray shale, called the Otisville shale member by Swartz and Swartz (1931). The appearance of the quartzitic beds is similar to the Binnewater Sandstone, so that this member appears to be a more shaly phase of that unit. It is overlain by red and green shales and sandstones of the Bloomsburg Formation (FIGURE 3).

There is no close stratigraphic control of the ore occurrences. The vein at Ellenville cuts the Binnewater Sandstone. At Spring Glen, Wurtsboro, and Otisville the veins are in the Shawangunk Formation, while the occurrence of Guymard is in the Otisville "shale member." In all cases, however, the wall rocks are tough, brittle quartzites and sandstones, with only minor shale interbeds.

Structure

The general structure of Shawangunk Mountain from Ellenville to Port Jervis is simple, the beds dipping consistently to the northwest, from 12° to 50° and striking N 10° to 30° E. The structure is essentially monoclinal, since there is neither a well-defined anticline to the southeast, nor a well-defined syncline to the northwest.

The ridge is cut by both reverse strike faults and by dip faults with essentially horizontal movement. Some of the faults are mineralized and are the principal controlling features of the ore deposits.

All of the mineralized faults are located near perceptible changes in the average strike of the beds and, conversely, all but one such change in strike in the area has an associated mineralized area. This relationship is shown by FIGURE 4. The straight lines represent average strike of observed beds in each area.

The Ore Deposits

All of the occurrences examined are fissure veins containing sphalerite, galena, pyrite, chalcopyrite, and quartz. Some replacement of breccia fragments was observed at most of the localities. In detail, however, each occurrence has distinctive characteristics.

Shawangunk Mine. The Shawangunk Mine is located at an elevation of 1100 feet on the western slope of Shawangunk Mountain, 2.4 miles N 77° E. of the center of the village of Wurtsboro.

The oldest workings consist of pits on the outcrop of the vein. The principal mining was carried out through an adit 230 long that starts at about the 1100-foot contour and intersects the vein about 100 feet below the crop. The vein was worked by sublevels and stopes, almost to the surface. An inclined raise connects the adit level drift with a 25-foot ver-

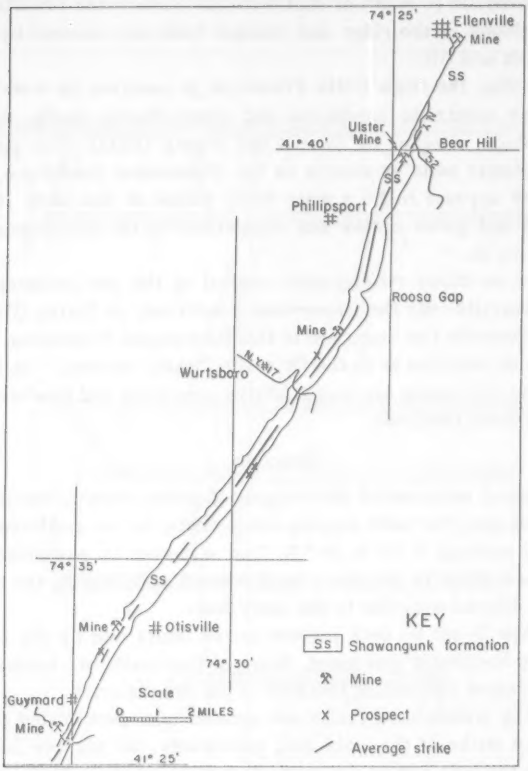
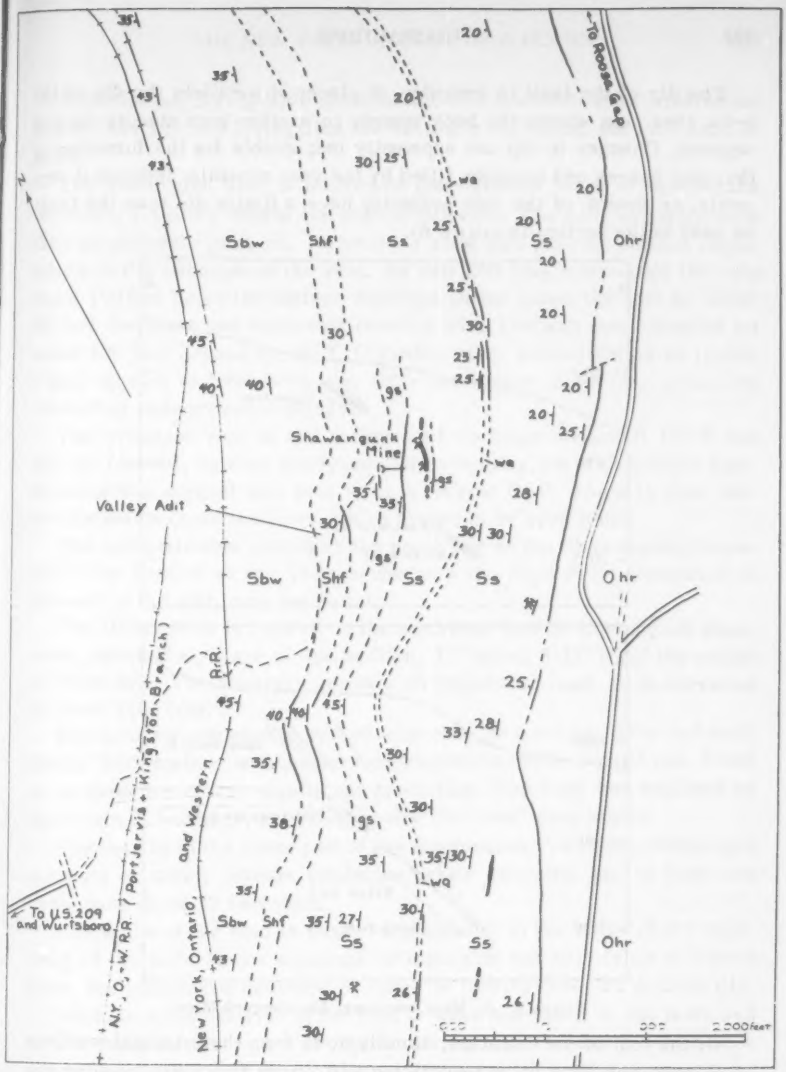


FIGURE 4. Outline map showing relation of strike changes to location of deposits.

tical shaft near the outcrop of the vein. The shaft is caved, but the rest of the workings are accessible and well-ventilated through connections with the near-surface workings. Some stopes below the level of the main drift are filled with water and are inaccessible. Surface drilling (Eilertsen, 1950) has proved a strike length of nearly 2000 feet.

The vein is located on a reverse fault that has a strike essentially parallel to the bedding, but the average dip is steeper. The vein cuts beds of the upper part of the Shawangunk Formation, which here consists of quartz sandstone (slightly arkosic) and conglomerate. Local mappable units of more pure, white quartzitic sandstone, and a less pure sandstone with scattered, dark, rock or mineral fragments ("green-specked" marker) are shown on the map and sections. Mapping of these units made it possible to demonstrate reverse movement on the fault, with a stratigraphic displacement of about 50 feet.



Sbw	Binnewater ss.	gs	green specked marker beds		
Shf	High Falls fm.	wq	white quartzite		
Ss	Shawangunk fm.	—	vein	⛏	shaft
Ohr	Hudson River series	>—	adit	⛏	prospect

FIGURE 5. Surface geology in the vicinity of the Shawangunk Mine.

The dip of the fault is irregular, at places it parallels the dip of the beds, then cuts across the beds steeply to another less steeply dipping segment. Changes in dip are apparently responsible for the formation of the open spaces and breccias filled by the vein minerals. Individual segments, or shoots, of the vein evidently have a flatter dip than the fault, as seen in the section (FIGURE 6).

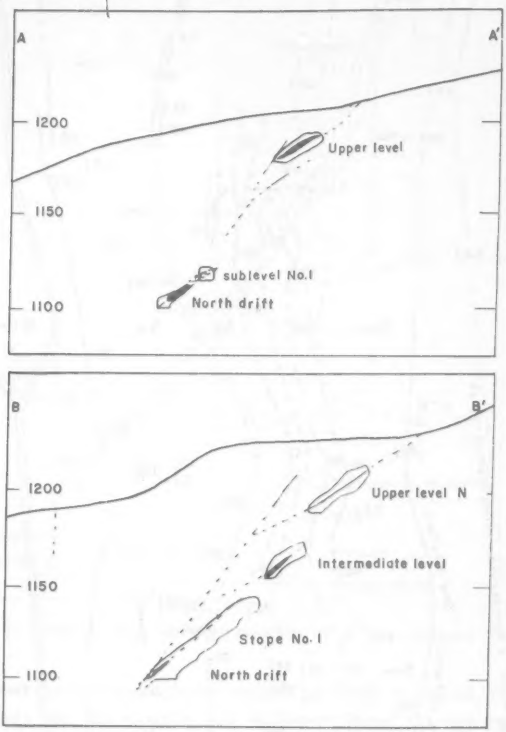


FIGURE 6. Mine sections, Shawangunk Mine.

At the foot of the mountain, directly down from the principal workings of Shawangunk Mine is an exploration adit driven to locate the down dip extension of the vein. The work was apparently done in the 1840s. The adit intersected a 6-inch-thick vein with some sphalerite mineralization 1100 feet from the portal. Drilling by the United States Bureau of Mines (Eilertsen, 1950) discovered a vein up to 6-feet thick about 100 feet beyond the end of the adit. A strike length of about 350 was proved by this drilling.

The mine and the results of the United States Bureau of Mines drilling are described fully by Eilertsen (1950) and Sims and Hotz (1951).

Otisville and Spring Glen occurrences. The occurrences of mineralization at Otisville and Spring Glen are similar to Wurtsboro, but on a smaller scale.

The Washington Mine is located on the northeast slope of Shawangunk Mountain, 1.1 miles west of the town of Otisville. The mine is hardly more than an elaborate prospect. A trench on some pits indicate surface exploration of the outcrops of the vein. An adit 260 long intersected the vein about 100 feet below the surface workings. Drifts follow the vein for about 60 feet northeast and southwest from the adit. The adit was extended for about 100 feet beyond the drift, following minor mineralization on joints. There appears to have been very little production of ore from either the surface or underground workings.

The principal vein in the underground workings strikes N 15° W and dips 55 feet NW, striking nearly parallel to bedding, but with steeper dips. Slickensides suggest this vein is on a reverse fault. There is also mineralization on cross fractures, which appear to be open joints.

The mineralization occurs in the upper part of the Shawangunk Formation. The contact of the Shawangunk with the High Falls Formation is exposed in the adit, near the portal.

The Ulster Mine is located on the northwest side of Shawangunk Mountains, above the village of Spring Glen, 3.7 miles, S 12° E. of the center of Ellenville. The workings are near an abandoned road, at an elevation of about 1100 feet.

The area was apparently worked only once, in the late 1830s and early 1840s. Both surface and underground exploration were carried out. There is no evidence of any significant production. The vein was explored by three sets of workings, extending nearly 1000 feet along strike.

The vein is in the lower part of the Shawangunk Formation, which here consists of slabby arkosic sandstone, white quartzite, and at least one shale zone about 30 feet thick.

The strike of the vein is essentially parallel to the strike of the beds. Drag of the beds in one exposure indicate that the vein is on a reverse fault, but conclusive evidence of offset is lacking here, as at Otisville.

Sulphide mineralization of the vein is weak and local. At the north end of the exposure the vein was intersected by a short adit. A 1-foot-thick quartz vein is the only mineralization. In the trenches near the south end of the exposure, the vein is 3 feet thick, and some sulphides are present. More highly mineralized specimens were found on the dump.

Guymard and Ellenville mines. The Guymard Mine is located 1600 feet N 40° E of Graham Station on the Erie Railroad, 8 miles northeast of Port Jervis, N. Y. The mine may be on the largest deposit in the district, but present exposures are very limited.

The vein was discovered and operation began in the 1860s. The mine was worked from a vertical shaft that eventually reached a depth of 365

feet. Ten thousand tons of ore were removed in 10 years of operation.

The vein is on a vertical cross fault that cuts the Otisville "shale member." The beds in the area strike N 75° E and dip 40° NW. The vein strikes EW and is essentially vertical. Beds on either side of the vein do not match, but the extend of offset could not be determined. It is felt that if the offset were more than 100 feet, it would be noticeable in the topography and nearby contacts. Drag on the beds indicates right lateral movement. Slickensides on the wall of the vein plunge steeply west.

The texture of the ore on the dump and the presence of gouge indicate a finer brecciation of the rock than at Wurtsboro. The stopes in the mine are said to have been 3 to 10 feet wide. The vein was presumably thinner in the intervening areas.

The Ellenville Mine is located at the southeastern edge of the town of Ellenville at the foot of Shawangunk Mountain. Although the mine is well known as a mineral specimen locality, very little could be learned concerning the now inaccessible workings. The mine was worked between 1853 and 1857 (Newland and Hartnagel, 1939, p. 107) and attempts to reopen it were made between 1901 and 1905. At that time the shaft was reported to be 200 feet deep.

The vein cuts beds of the Binnewater Sandstone, a gray, fine-grained, hard, quartz sandstone. The beds strike N 32° E. and dip 45° NW.

The vein is located on a cross fracture that strikes N 40° W to N 45° W, and has a vertical to steep NE dip. There is no indication of offset on the fracture in the surface exposures; beds appear to match across the fractures. The width of the vein seems to have been similar to that at Guymard. There is also some suggestion that the mineralization spread out along the bedding planes, away from the cross fracture.

Mineralogy and ore textures. The mineralogy of the deposits is simple and consistent throughout the district: quartz is the only nonsulphide gangue mineral, and sphalerite, galena, pyrite, and chalcopyrite are the only sulphides present. One grain of a mineral identified as pyrrhotite was found in a polished specimen of sphalerite ore from Ellenville. Intergrowths of sphalerite and chalcopyrite are common. Native gold is present at the Shawangunk and Ulster mines. The galena is known to be argentiferous at Wurtsboro and Guymard. The sphalerite is unusually dark brown in color, indicating a high iron content.

The textures of the ores include fissure filling, breccia filling, and replacement, so that most of the textures typical of other Appalachian lead-zinc ores are represented. The best information on ore textures is from Shawangunk Mine, where the workings are still completely accessible.

The narrow, high-grade parts of the vein are massive intergrowths of quartz and sphalerite with scattered grains of galena, chalcopyrite, and pyrite. Crude banding is given by alternations of bands of quartz with bands rich in sulphide.

The wall rocks of the vein generally show more or less fracturing, the

fractures being mineralized with quartz and sulphides for several feet from the vein. FIGURE 7 shows the vein in a pillar in the mine with mineralized fractures above and below the vein.

FIGURE 7. Vein and crackle breccia, Shawangunk Mine.

Brecciation is more intense near changes in strike and dip of the vein. Here there are developments of rubble breccia containing disoriented fragments of sandstone in a matrix of quartz and sulphides that reach as much as 6 feet in thickness. FIGURE 8 is a good example of this type of breccia in the hanging wall of the vein. FIGURES 9 and 10 show that in these breccias the sandstone fragments served as nuclei for sulphide deposition. There is also the suggestion, particularly in FIGURE 10, that there was some replacement of the sandstone nuclei. This replacement was fairly extensive if it is assumed all of the masses of sphalerite, which now show no sandstone centers, originally had them. In polished section there is also evidence of replacement of early quartz by sphalerite.

In the other occurrences of the district, the ore textures are generally finer grained, and the relations are not well known since little ore was seen in place. Both massive and breccia textures were seen. At Guymard and Otisville, there was fairly good evidence of replacement of breccia fragments of sandstone by sulphides. A piece of fine-grained ore found on the dump at Guymard suggests replacement of a siltstone by sulphides

FIGURE 8. Vein and cockade breccia, Shawangunk Mine.

FIGURE 9. Breccia at Shawangunk Mine showing various degrees of replacement of sandstone fragments.

FIGURE 10. Specimen showing partial replacement of sandstone fragment by sphalerite.

although the only existing description of the underground workings (Grugan, 1918) indicates the deposit was primarily a fissure filling.

At Ellenville the principal deposition was by fissure filling. There is also a suggestion (Ihlseng, 1903) of considerable mineralization of small fractures of crackle breccia texture. Mineral specimens from Ellenville show beautiful development of quartz crystals on slabs and living vugs, indicating more open texture than seen at Wurtsboro.

Paragenesis. Microscopic examination of polished specimens from all of the district shows the following features in common: (1) early quartz (including sand grains) is usually corroded by sphalerite, but not extensively replaced; (2) sphalerite is intergrown with contemporary quartz in space fillings; (3) sphalerite is replaced by pyrite, chalcopyrite, and galena; and (4) chalcopyrite-sphalerite intergrowths are common, and apparently both replacement and unmixing are responsible for the origin of the textures.

The paragenetic sequence is shown in FIGURE 11.

FIGURES 12 and 13 are typical examples of the sphalerite-chalcopyrite intergrowths. It is felt that the oriented lines of chalcopyrite inclusions are controlled by the cleavage of the sphalerite and represent replacement, while scattered grains, particularly those with regular outlines represent grains formed by unmixing. It may be that all of the intergrowths of the type shown are the result of unmixing.

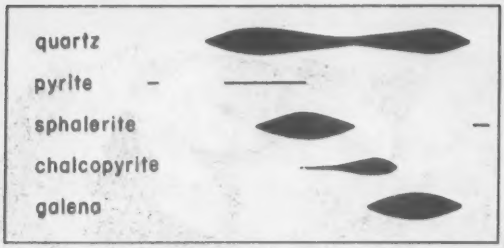


FIGURE 11. Paragenetic diagram.

Experimental work by Buerger (1934) has shown that intergrowths of sphalerite and chalcopyrite of the type seen here disappear on heating, that is, the chalcopyrite is redissolved in the sphalerite. Although the phase relations of chalcopyrite and sphalerite have not as yet been fully worked out, there is at least the suggestion that the intergrowths represent exsolution of chalcopyrite on cooling. Buerger found that remixing took place at about 350° C.

Ore grade and zoning. The tenor of the ore is known in detail only at the Shawangunk Mine, where extensive drilling and sampling was done by the United States Bureau of Mines (Eilertson, 1950). Enough is known about the other deposits to suggest a regional pattern of metal ratios.

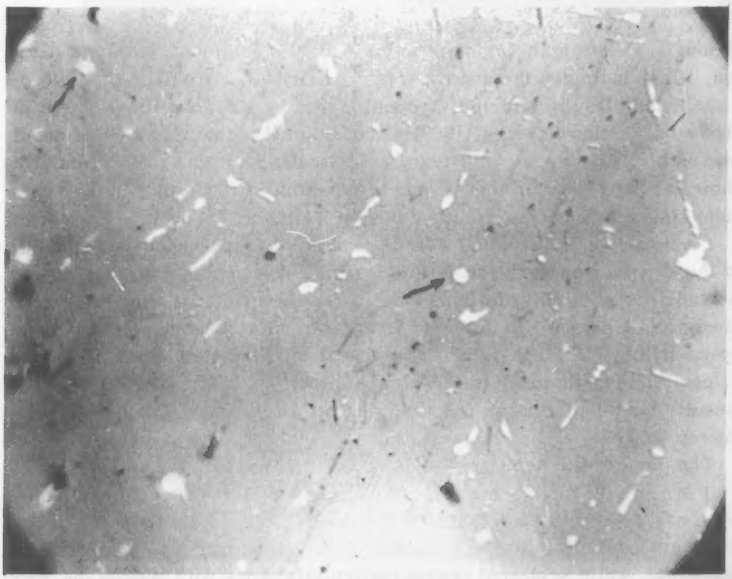


FIGURE 12. Chalcopyrite-sphalerite intergrowth. Arrow points to regular shaped grain of chalcopyrite interpreted as forming by exsolution. X300.

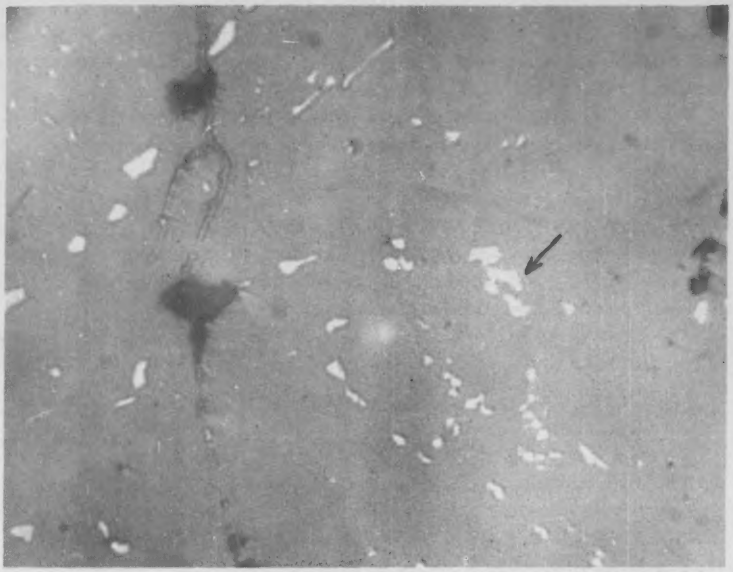


FIGURE 13. Chalcopyrite-sphalerite intergrowth. Arrow points to irregular grain of chalcopyrite, formed by replacement.

At Guymard, Grugan (1918) reported an average grade of 13 per cent lead and 14.5 per cent zinc. He does not mention copper, and chalcopyrite is relatively scarce in the ore specimens seen. In the Shawangunk Mine at Wurtsboro, in the upper workings and drill holes the grade runs from 5 to 10 per cent zinc and 1 to 5 per cent lead. Copper is reported in amounts generally less than 1 per cent. The ration of zinc to zinc to Pb in the upper workings is about 2:1. There is a regular increase of this ratio with depth and, in the holes drilled from the valley level adit, the ratio reached about 7.1.

At Ellenville the only reports of grade (Ihlseng, 1903) indicate values as high as 20 to 30 per cent zinc and 6 to 12 per cent Cu; lead is not mentioned.

The over-all picture is a general increase of zinc and copper in relation to lead going from Guymard to Otisville. At Wurtsboro there is also evidence of an increase of zinc with depth.

Origin. The features of the deposits described above give a number of suggestive clues to their mode of origin.

There is a clear-cut structural control to the localization of the deposits. The openings formed by tectonic movements of various types clearly acted as channel ways for the ore-bearing solutions.

The regular regional variation in metal ratios suggests a regional sys-

tem of mineralization, in which systematic changes of composition took place apparently as a function of distance from a central source. The limited distribution and linear arrangement of the occurrences obscures any clear-cut definition of such a source.

Mineral deposition is primarily by space filling, but there is clear evidence of replacement of quartz sandstone fragments in the breccias. It is apparent that the solution had the power to dissolve quartz. Quartz is essentially the only nonmetallic gangue mineral.

The exsolution textures of sphalerite and chalcopyrite suggest deposition under conditions of elevated temperature. This is also confirmed by Friedman (1959), who reports that his work on sphalerite geothermometry of specimens at Ellenville indicate a temperature of 325° C.

The above features indicate to me that the deposits were formed by hot solutions capable of solution and transport of silica and originating from a local center: in other words, hydrothermal solutions.

Summary

The zinc deposits of the Shawangunk Mountains will never be an important source of base metals, due to the limited tonnages present. Their study is of interest only through comparison with more important zinc-lead deposits of the Appalachian region.

Like the deposits at Friendville, Pa., Austinville, Va., and in east Tennessee, the deposits are in sedimentary rocks and far from any visible igneous source. The Shawangunk deposits are in clastic rocks rather than carbonates. The carbonates are possibly more favorable hosts, but are not essential to ore formation.

The mineralogy is simple in all of the deposits. The Shawangunk deposits differ principally in the presence of quartz gangue, while the deposits in carbonate rock have carbonate gangue minerals as well as quartz. Clearly the composition of the wall rocks is reflected in the com- of the gangue.

The ore emplacement is by fissure filling and replacement. The ore textures, particularly the breccia textures in the Shawangunk deposits, are very similar to the textures of the deposits occurring in carbonate rocks.

Structural control is clearly indicated in the Shawangunk district as it is at Austinville. Tectonic movements formed openings that provided channel ways for movement of the solutions and space for deposition. There is no question that the breccias at the Shawangunk mine are of tectonic origin, yet the resulting breccia ore textures are very similar to those at Friendville and elsewhere, for which sedimentary origin has been argued.

One final unifying factor is the absence of any visible source of hydrothermal solutions, such as igneous intrusion of metamorphism. Yet the

mineralogy and textural relationships do indicate that the mineralization has a hydrothermal origin.

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THE FINE STRUCTURE OF THE GOLGI BODY FOLLOWING THYROID STIMULATION AND PANCREATIC REGENERATION*

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Introduction

The Golgi complex has been extensively described morphologically at both the light and electron-microscope levels (see review papers by Worley, 1946; Dalton and Felix 1954; Palay 1958). Its association with secretion has long been recognized. This paper will attempt to relate the production of secretory granules by the Golgi vesicles in salamander thyroid cells following TSH administration and in rat pancreas exocrine cells during a regenerative phase following earlier destruction by ethionine.

Materials and Methods

*Salamander thyroids.*** Adult *Ambystoma tigrinum* salamanders were injected daily with 0.1 mg. thyroid-stimulating hormone (TSH).† At the end of one and two weeks the animals were sacrified and the thyroids removed and prepared for light and electron microscopy.

Rat pancreas.‡ White male rats of the Wistar strain weighing approximately 120 to 180 gm. were placed on a protein-free diet.§ One half of this group were injected intraperitoneally daily with DL-ethionine (0.7 mg./gm. body weight) for a period of 10 days. The remaining animals served as controls. At day 10, maximum destruction to the pancreas acinar cells had occurred. Surviving animals were then permitted to enter the regenerative phase, and groups of animals were sacrificed at days 12, 18, and 28 following the start of the experiment (2, 8, and 18 days after the last ethionine injection). Techniques of fixation have been described (Herman *et al.*, 1958; Herman and Fitzgerald. §§

*This paper, illustrated with slides, was presented at a meeting of the Section on January 9, 1961. The investigation reported in this article was supported in part by Research Grants C-3301 and A-2548 from the National Cancer Institute and the National Institute of Arthritis and Metabolic Diseases, Public Health Service, Bethesda, Md.

**For details of the experimental design see Herman, 1960

†D. A. McGinty of Parke Davis & Co., Detroit, Mich. kindly supplied the TSH preparation.

‡For details of the experimental design see Herman *et al.* 1960.

§Nutritional Biochemicals Corp., Cleveland, Ohio.

§§Herman, L. & P. J. Fitzgerald. 1961. The degenerative changes in pancreatic acinor cells caused by DL-ethionine; an electron microscope study. In preparation.

The Section of Chemical Sciences held a meeting on January 3, 1961, at which Ronald Breslow of the Department of Chemistry, Columbia University, New York, N. Y., presented a paper entitled "Aromaticity in Cyclopropene Derivatives." This paper will not be published by the Academy.

Results

Salamander thyroids. The epithelial cells of the normal thyroid gland of the adult salamander, *Ambystoma tigrinum*, appeared as a group of flat cells with scant cytoplasm and elongated nucleus surrounding a large, slightly dense lumen. Following the daily administration of TSH for a period of one to two weeks, the cell height and nuclear volumes increased to three times that of the normal. Fine structural changes occurred in the ergastoplasm, secretory droplets, and microvilli as well as the Golgi.

The Golgi zone of the normal thyroid follicle cell. In the cytoplasm adjacent to the nucleus, the Golgi zone appeared as a small area containing a series of flattened, agranular, membrane-enclosed vacuoles surrounded by numerous smaller vexicles. The vacuoles were usually empty or contained a small amount of lightly stained material, and the surrounding vesicles contained variably dense material (FIGURE 1*a*).

The Golgi zone of the TSH-stimulated thyroid follicle cell. With progressive THS administration the Golgi zone became enlarged. The smooth-surfaced membranes, vacuoles, and vesicles increased in size and number. The cytoplasmic area within and adjacent to the Golgi zone contained many vesicles and secretory granules of variable size and density. A progression of vesicles could be followed between the smallest vesicle, containing less dense material of variable density, and the largest, which contained a homogeneously dense material most closely resembling a mature secretory granule (0.5 to 1.0 μ in diameter).

Rat Pancreas

The Golgi zone of the normal acinar cell. Several electron-microscope studies have been made of normal and abnormal rat pancreas, and some attention has been given to the Golgi substance and its role in the synthesis of mature zymogen granules, (Palade, 1955, 1956; Sjostrand and Hanzon, 1954; Farquhar and Wellings, 1957; Weiss, 1953, 1955; Herman *et al.*, 1958; Herman and Fitzgerald*; Herman *et al.*†; B. Weisblum *et al.*‡. In the normal pancreas it is believed that the Golgi vacuoles receive the products of synthesis from the endoplasmic reticulum and package them as final products of secretion in the form of zymogen granules. Frequently one may see one or two small prozymogen granules within the central portions of Golgi vacuoles (FIGURE 3).

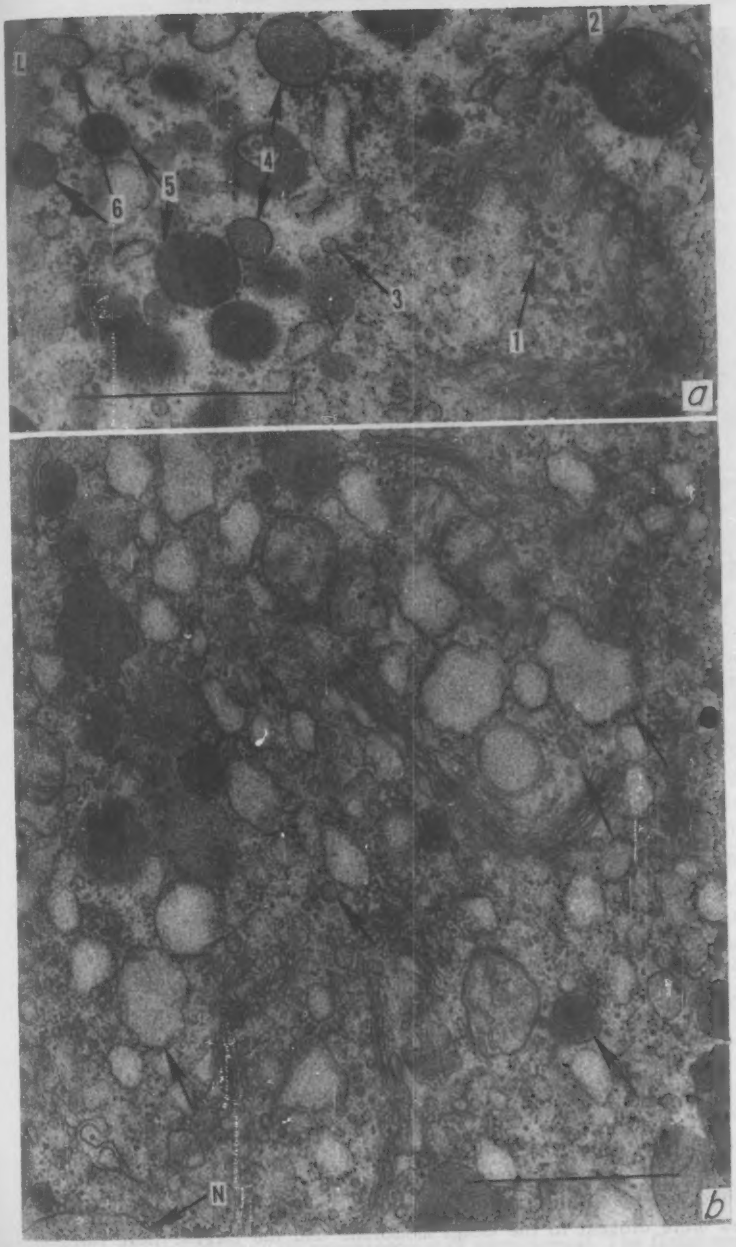
The Golgi zone of the regenerating acinar cell. Ten daily intraperitoneal injections of ethionine resulted in the selective destruction of the

*HERMAN, L. & P. J. FITZGERALD. 1961. The degenerative changes in pancreatic acinar cells caused by dl-ethionine; an electron microscope study. In preparation.

†HERMAN, L., B. WEISBLUM & P. J. FITZGERALD. 1961. The regenerative changes in pancreatic acinar cells following ethionine administration; and electron microscope study. In preparation.

‡WEISBLUM, B., L. HERMAN & P. J. FITZGERALD. 1961. The fine structure of the rat pancreas during protein deprivation. In preparation.

FIGURE 1a. *A. tigrinum* normal follicle cell. The Golgi area appears on the right and consists of closely arranged parallel membranes and small vesicles. Some of these vesicles contain a moderately dense material. Between the Golgi and the lumen (*L*) in the upper left corner a variety of vesicles and granules appear bounded by a single membrane. The sequence of granule maturation appears to be as follows: vesicles at arrows 1, 2, and 3 within the Golgi zone are immaturely formed and partially filled with secretory material; those at arrow 4 are more advanced in their formation, and those at arrow 5 represent the mature secretory granules. It would appear that granules at the free-cell border (*arrow* 6) empty into the lumen; the uppermost of the two seems to have opened into the colloid and the lower one appears to be prepared to do the same × 33,500. (*b*). *A. tigrinum* follicle cell following 16 days of TSH. The Golgiares is larger with more membranes, vacuoles, and vesicles present. The vesicles and vacuoles have variable densities within and around the Golgi zone (*arrows*). *Compare with a* at the same magnification. × 33.500.


L
1
2
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5
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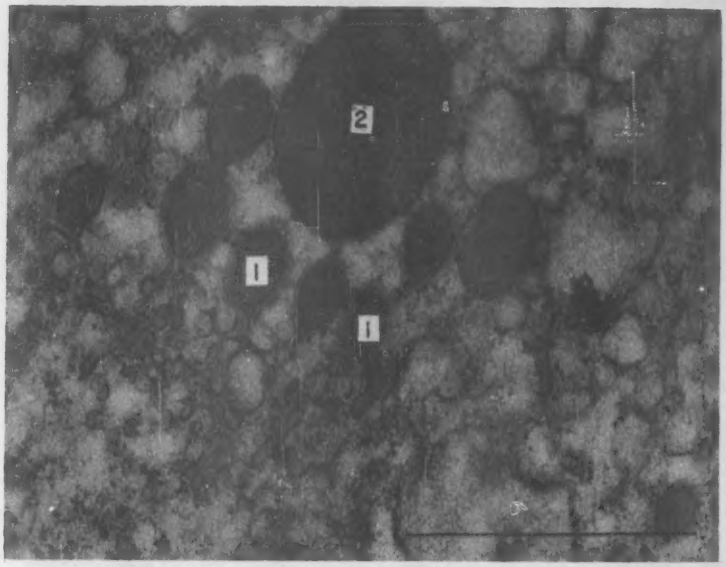


FIGURE 2. *A. tigrinum* follicle cell following 6 days of TSH. Reproduced by permission of the Rockefeller Institute Press, New York, N. Y. (L. Herman, 1960) The Golgi area appears in the lower left appearing as numerous vesicles with some having an internal density slightly higher than background. An intermediate stage of granule formation appears at 1, and a mature granule at 2. ×46,000.

exocrine cells of the rat pancreas. Electron microscopy studies showed the endoplasmic reticulum to be the first cytoplasmic structure affected. This organelle became progressively more disoriented, and by 10 days showed considerable destruction followed by disturbances to mitochondria zymogen granules and the Golgi apparatus (Herman and Fitzgerald, op. cit.) At day 12, a period of early regeneration, the Golgi zone was characterized by small vacuoles, agranular membranes, and many small vesicles. Between the Golgi zone and the free apical cell border numerous partially filled vesicles were found. The mature zymogen granules (approximately 0.5 to 1.0 μ in diameter) were absent and replaced by similar, smaller granules (0.1to 0.2 μ in diameter) shown in (FIGURE 4).

At day 18 (day 8 of regeneration) the Golgi was enlarged, (Herman Weisblum and Fitzgerald, op. cit.). It extended from one lateral wall of the cell to the other and occupied the entire centrosphere region. There were many agranular membranes in close apposition to each other. These occasionally spread to form vacuoles. Surrounding these membrane-enclosed vacuoles were numerous vesicles. The smallest, least dense vesicles were closest to the Golgi membrane and the largest were farthest

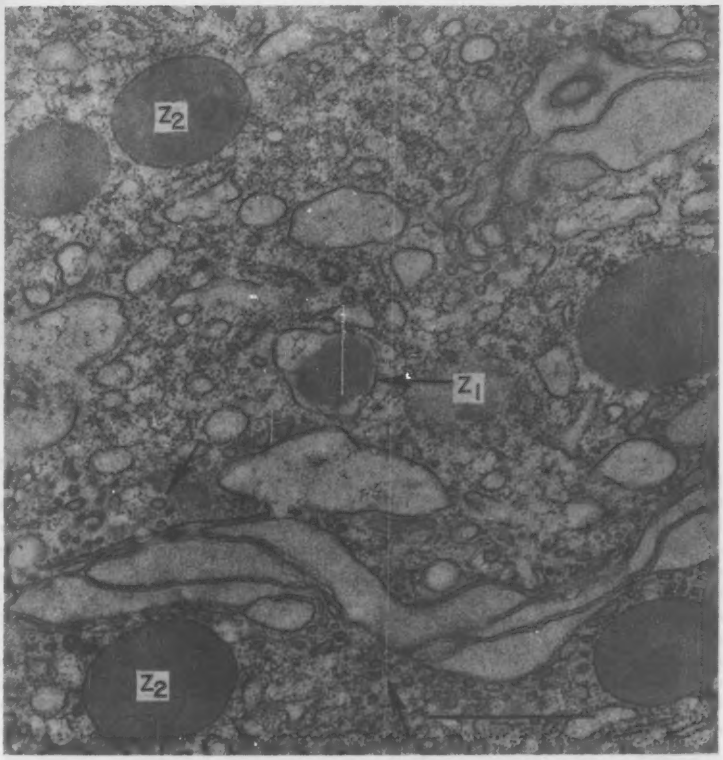
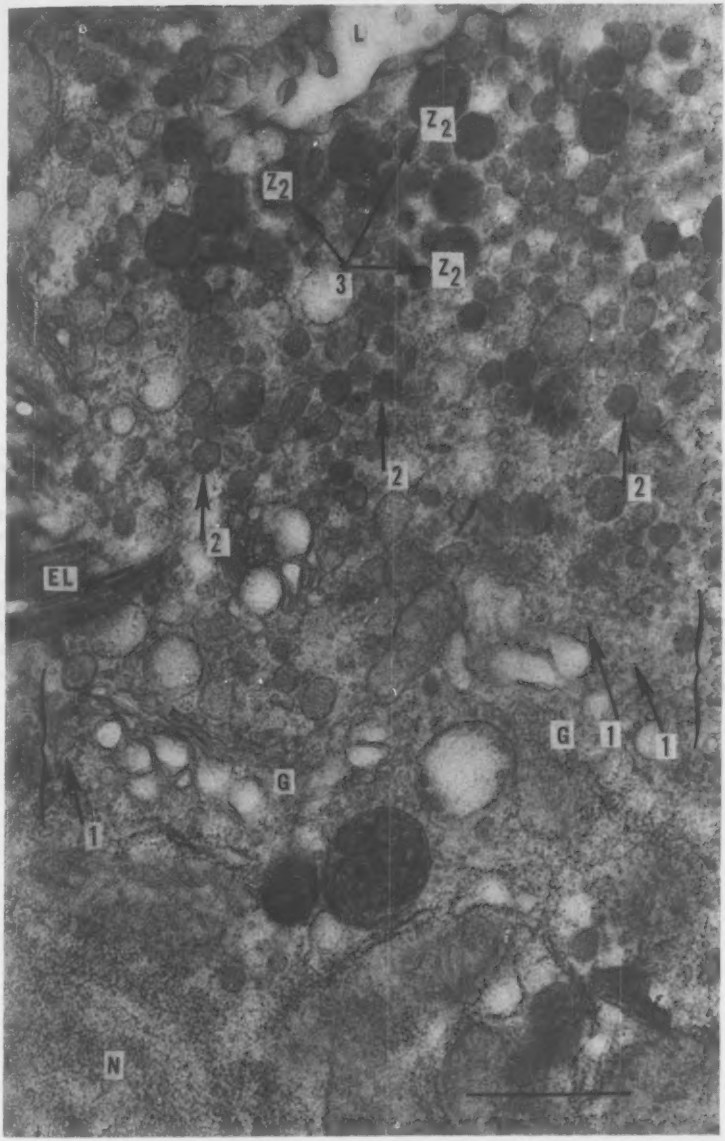


FIGURE 3. Normal pancreatic acinar cell of the rat. The Golgi body consists of smooth-surfaced membranes that enclose fusiform vacuoles. An immature zymogen granule appears in a Golgi vacuole at Z_1. A number of small Golgi vesicles (*unmarked arrows*) lie adjacent to the membranes. Mature zymogen granules appear at Z_2. ×26,000.

away. There were few instances of prozymogen granules within Golgi vacuoles as is frequently seen in a stock-diet pancreas. In the apical region of the regenerating acinar cell were numerous vesicles similar to those surrounding the Golgi membranes. These filled the area normally occupied by mature zymogen granules. These vesicles were variable in size and density, the larger ones being approximately 0.25 μ in diameter and bearing a close resemblance to small zymogen granules (FIGURE 5 and 5*a*). It appeared that the enlarged Golgi at day 18 produced numerous small vesicles that progressively enlarged and became filled with a homogeneous material that moved to the apex of the cell.

At day 28 the acinar cell appearance was more normal. The Golgi zone

FIGURE 4. Pancreatic acinar cell of an animal at day 12 (2 days after the last ethionine injection): compare with the normal FIGURE 3 at the same magnification. The cell is decreased in size. A portion of the nucleus (*N*) is in the lower left corner and the lumen (*L*) appears at the extreme upper center. Part of a persistant cytoplasmic lesion (*E.L.*), appearing as a dense osmiophilic plaque of fused membranes, may be seen. The Golgi zone (*G*) lying between the brackets, has lost its elongate, membranous appearance and consists of round vacuoles devoid of prozymogen granules. Compare with Z_1 of FIGURE 3. Between the Golgi zone and the lumen a variety of vesicles and granules have formed. The smallest and least dense (*arrows* 1), appear within and adjacent to the Golgi. Intermediate forms (*arrows* 2) are slightly larger and denser. Mature miniature granules (*arrows* 3) represented by Z_2 are near the luminal surface. These small zymogen granules may be compared at the same magnification, with the more normal appearing stock diet zymogen, Z_2, of FIGURE 3. × 26,000.


L
Z2
Z2
3
Z2
2
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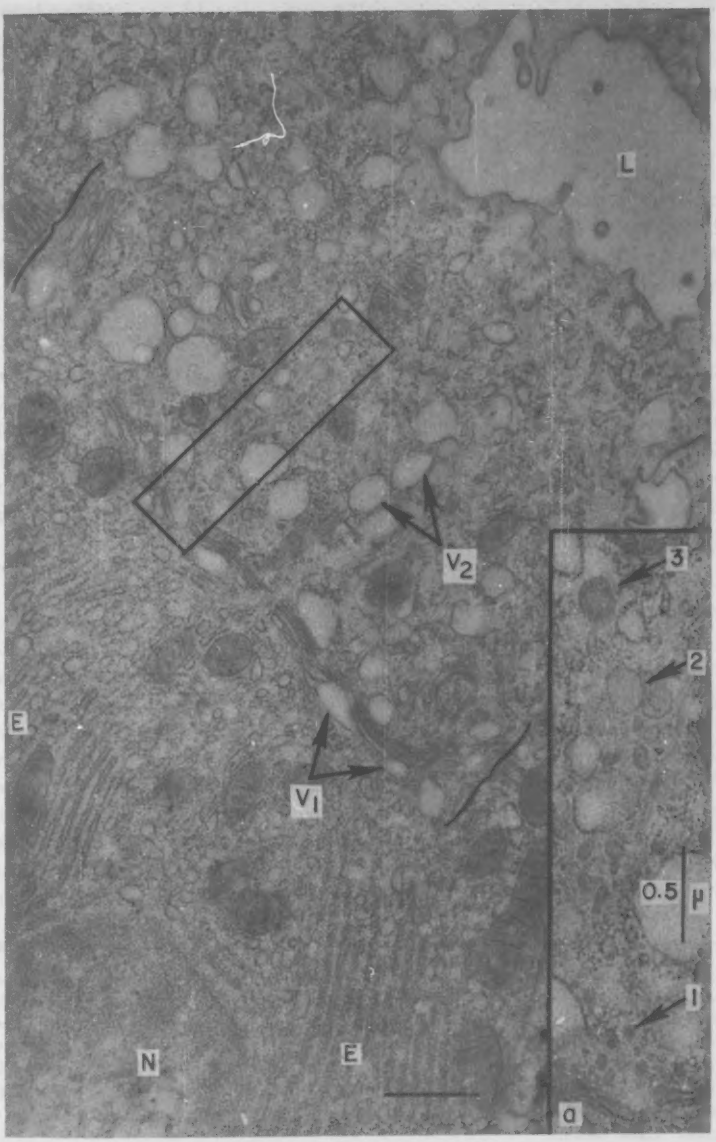
2
EL
G
1
1
G
1
N

FIGURE 5. Pancreatic acinar cell of an animal at day 18, (8 days after the last injection). A portion of the nucleus (*N*) appears in the lower left, and part of the lumen (*L*) appears in the upper right. Arrays of regenerating ergastoplasm (*E*) appear as parallel membranes on either side of the nucleus. The Golgi body occupies the width of the cell extending across the centrosphere region between the brackets. It consists of flattened closely apposed membranes that occasionally dilate to form a vacuole (V_1). Scattered about the apical cytoplasm are numerous vacuoles (V_2) and vesicles with varying densities. Few of these appear below the Golgi zone. ×15,000. (*a*) An enlargement of the enclosed area of FIGURE 5 demonstrating the maturation of granules between the Golgi and the luminal border of the cell. Maturation presumably proceeds from arrow 1 to arrow 3. ×30,000.


L
V2
3
2
E
V1
0.5 μ
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N
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was reduced in size with fewer membranes and larger rounder vacuoles. The small vesicles in the apex of the cell of day 18 had been replaced by large, normal, mature zymogen granules. It was evident that the hypertrophied Golgi of day 18 had returned to or been replaced by a Golgi apparatus of more normal appearance (FIGURE 6).

Discussion

Salamander Thyroids. At the light-microscope level the TSH induced changes in salamander thyroid have been admirably described (Figge and Uhlenhuth, 1933; Schwartzback and Uhlenhuth, 1936; Uhlenhuth *et al.*, 1945*a*; 1945*b*). A similar electron microscope study of these changes has been published recently (Herman, 1960).

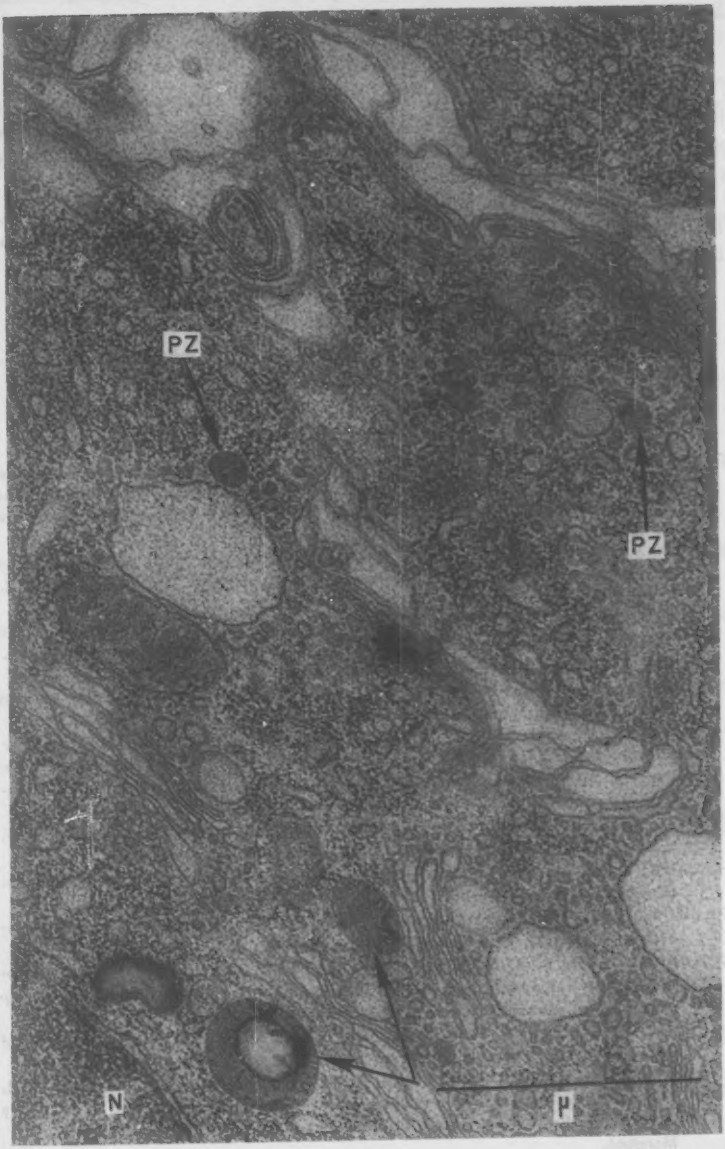
With TSH administration the numbers and size of secretory granules increase in the follicle cells. A progression of granule sizes may be traced from the Golgi zone to the periphery of the cell and it would seem that such a sequence suggests that the mature secretory granule originated as a result of the filling or concentration of material within the small Golgi vesicles followed by enlargement and migration away from the Golgi region, (FIGURES 1*b* and 2). A similar suggestion has been offered for the formation of secretory droplets in the Golgi of rat thyroid cells (Wissig, 1960).

Rat pancreas. During regeneration of the acinar cells of the pancreas considerable changes occur in the morphology of the Golgi body.

At days 12 and 18 the presence of 1 or 2 normally occurring intracisternal granules within Golgi vacuoles was absent. Instead, numerous variably dense small vesicles were seen. It appears that during regeneration the Golgi structures increase in amount and are associated with an alternative method of zymogen production. This method possibly consists of production of small vesicles that are pinched off the lamellar structure. Such a pinching-off process resulting in vesicular formation has been suggested by others (Worley, 1946; Dalton and Felix, 1955). These vesicles may gather material and migrate to the apex of the cell resulting in the formation of small dense miniature zymogen granules. When later states of regeneration have been achieved, as at day 28, the Golgi then

FIGURE 6. Pancreatic acinar cell of an animal at day 28 (18 days after the last ethionine injection). A portion of the nucleus (*N*) appears in the lower left. Extensive arrays of Golgi membranes, vacuoles, and vesicles fill the field. Some of the vesicles and vacuoles contain a density within. One or two small structures (*P.Z.*) seem to have a density similar to that of a mature zymogen granule. If these represent immature granules (prozymogen) it is of interest to note that, unlike the normal, they are small and not within a Golgi vacuole surrounded by a clear "halo" area.

Large granules (one with a clear central area) containing fragments of dense osmiophilic membranes within appear at the unmarked arrows. ×41,000.


PZ
PZ
N
P

appear more normal in appearance and presumably function in more normal fashion (FIGURE 6).

Summary

A possible mechanism for the production of secretory granules has been described for the TSH-stimulated thyroid follicle cell of the adult salamander *A.tigrinum* and the pancreatic acinar cell of the rat during stages of regeneration.

This consists of the production of small vesicles in the Golgi zone, their progressive migration and filling with secretory material resulting in the production of a mature secretory granule.

Acknowledgments

We express our sincere appreciation to Bernard Weisblum, Alan Lieberman, and Charles Harman for their technical assistance.

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ORIGIN AND FATE OF SECRETORY GRANULES IN CELLS OF THE ANTERIOR PITUITARY GLAND*

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The assumption that stainable granules represent stored secretory products has long been a basic tenet in pituitary cytology, as in the study of many other glands. In the last decade, the application of newer techniques in this field has led to a general belief that each pituitary hormone is contained within specific granules that are produced by independent cell types. There is now rather convincing evidence derived from histochemistry, cytochemistry, and electron microscopy, relating hormonal content to "specific" granules for each of the known anterior lobe hormones except ACTH. In the case of the gonadotrophic hormones, a characteristic ($\sim$ 200 μ M) granule fraction containing most of the hormonal activity has been isolated in remarkably pure form.[1] Hence we can justifiably assume that further understanding of the cellular processes involved in hormonal production and release may be achieved by following the origin and fate of secretory granules. Electron microscopic studies reported here and elsewhere[2-4] indicate that the mechanisms involved in the formation, transport and release of secretory granules are basically similar in all granulated cell types of the anterior lobe of the rat pituitary.

Granule Formation Within the Golgi Complex

Many small granules of varying size can be seen in the Golgi region of active cells (FIGURE 1). In many instances all expected "intermediate" forms between small Golgi vesicles and mature secretory granules can be found. The small forms often show a lighter halo of variable width between the dense content and surrounding membrane. Sometimes also what appears to be an immature granule(s) is present within a larger Golgi cisterna limited by a smooth-surfaced membrane. These appearances suggest that secretory granules originate within the Golgi zone and are formed by a gradual filling of Golgi cisternae with dense material.

In contrast to the situation encountered in the Golgi zone, the size of granules found in other regions of a given cell (when allowance is made for level of sectioning) is relatively uniform and has been used as one criterion for distinguishing between cell types.[5-7] Furthermore (with one exception to be mentioned below), granules located outside of the Golgi region as a rule do not show a lighter halo between the dense content and the membrane; moreover, because of similar density and close apposition to the content, the membrane is not clearly visible. It is pre-

*This paper, illustrated with slides, was the second of three papers presented at a meeting of the Section on January 9, 1960.

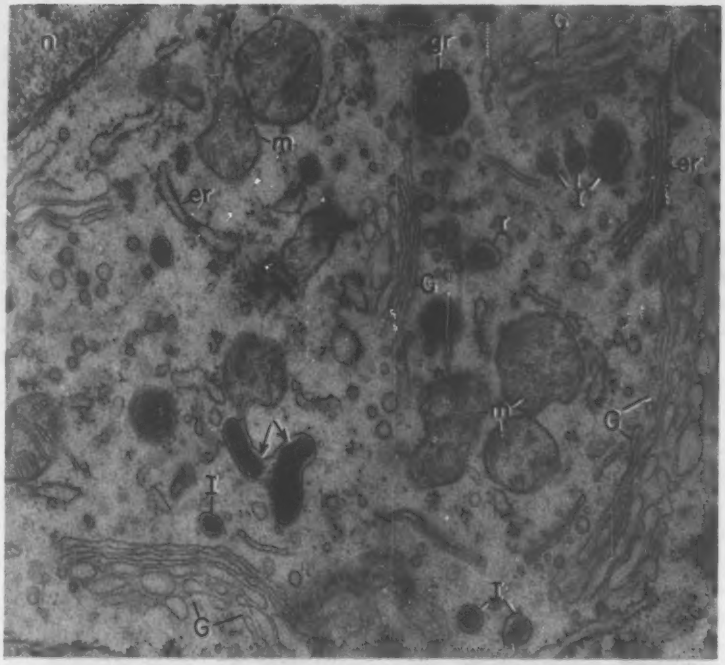

FIGURE 1. Golgi zone of an acidophil (lactogenic hormone type)[7,15] from a rat pituitary. Several stacks of smooth surfaced Golgi cisternae (G) and vesicles are shown. A number of small or immature granules (I) are present within Golgi vesicles. In one place (*arrows*) two elongated dense masses (presumed to represent forming granules) are seen within a large Golgi cisterna.

Key: er, endoplasmic reticulum with attached RNP particles; m, mitochondria; n, nucleus; gr, mature granule. ×27,000.

sumed that these granules found in the intermediate and peripheral cytoplasm represent mature forms that are stored until discharged.

Granule Discharge

In the anterior lobe cells secretory granules are commonly concentrated immediately beneath the cell membrane forming a peripheral rim. In this location, as in the Golgi region, many of the granules have membranes more loosely applied to the dense content (FIGURE 2*a*, *c*), and sometimes two granules share a common envelope (FIGURE 2*a*). Occasional granules show continuity of their membrane with that of the cell (FIGURE 2*a*-*c*), suggesting that the granule membrane has fused with the cell membrane. Through the stoma thus formed the content is apparently released into the surrounding spaces. In some instances the plasma

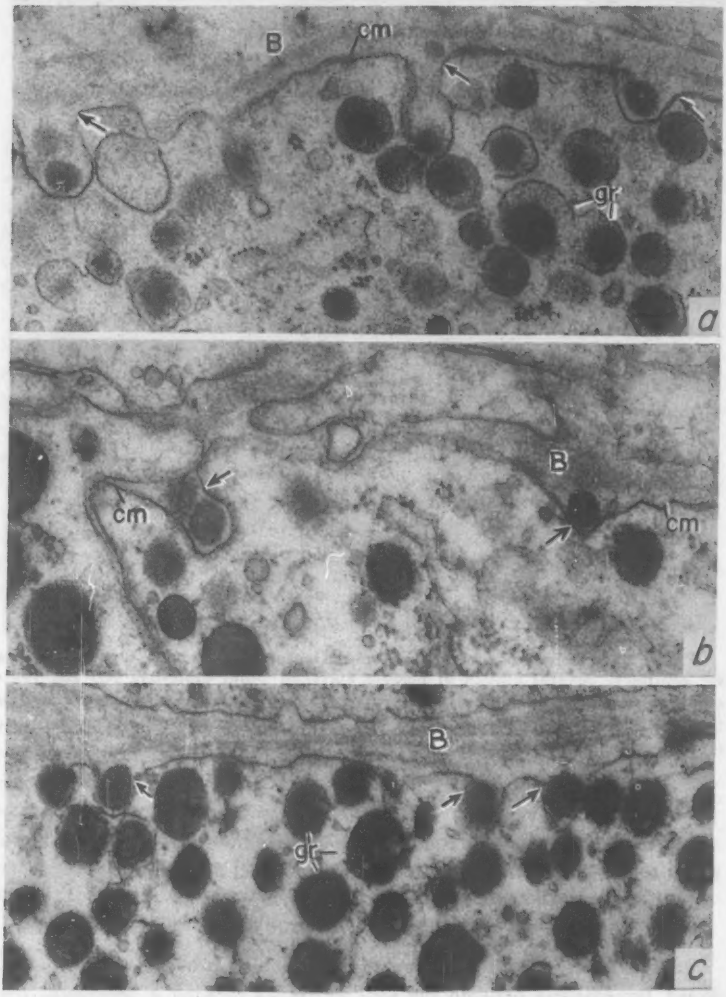

FIGURE 2. Vascular pole of several anterior lobe cells, showing numerous granules in the process of discharging their contents into the perivascular connective tissue. Continuity of granule membrane and cell membrane (cm) can be seen in a number of places (*arrows*). In *b* the cell membrane (cm) is infolded at at the site of granule release. In a two granules (gr) share a common envelope. Key: B, basement membrane; *b*, gonadotrophic basophil, ×38,000; *a* and *c*, acidophils of the growth hormone type[8 II], ×60,000 and 36,000.

membrane is infolded over the point of continuity (FIGURE 2*b*), indicating that it may invaginate to meet the granule membrane. Granules undergoing discharge are often found at the vascular pole of the cell facing the basement membrane of the capillary but are less commonly encountered in the intercellular spaces between parenchymal elements. It is of interest that the dense granule cores maintain their spherical shape and are clearly visible immediately after membrane mergence; however, none has been found lying free in the perivascular connective tissue or within the vascular endothelium. It is therefore assumed that the dense content rapidly dissolves or undergoes some physicochemical change in the environment of the space to a form no longer visible. In this invisible form the contained hormones or precursors presumably are transferred to the blood stream.

Discussion

On the basis of the findings presented it is suggested that the secretory granules of anterior lobe cells are formed within the cisternae of the Golgi complex. After reaching maximal size they apparently move out peripherally in the cytoplasm, eventually aggregating along the cell membrane. Upon appropriate stimulus, the granules are released—primarily into the perivascular spaces—by mergence of the granule membrane and cell membrane. It follows that during its entire life cycle, the granule content is separated from the cytoplasmic matrix by the smooth-surfaced membrane acquired in the Golgi zone.

The Golgi apparatus has long been associated with the process of granule formation,[8,9] and this association has been further strengthened by electron-microscopic studies. At the electron-microscope level the presence of immature granules in the Golgi zone (suggesting formation at that site) was first seen by Sjöstrand and Hanzon[10] in pancreatic acinar cells and has been described many times in pituitary cells[2-4,9,11-15] as well as in other tissues.[9] Although the electron microscopic evidence clearly implicates the Golgi complex in granule formation, little information is available on the sites of actual synthesis of pituitary hormones; however, other recent evidence summarized elsewhere[3,9] strongly supports the classical contention[16] that the Golgi apparatus may act as a "condensation membrane for the concentration in drops or granules of products elaborated in other locations that diffuse through the cytoplasm."

The observations on the mechanism by which granules are discharged from cells of the anterior pituitary represent a newer finding.[4] Similar observations have also been reported independently by Lever and Peterson[13] in one cell type of the anterior lobe. The release of secretory products by fusion of granule membrane with the cell membrane was first described by Palade[17] in exocrine cells of the pancreas. In the case of the pancreas, the zymogen content loses its spherical shape upon dis-

charge and pours out into the acinar lumen, whereas the dense component of pituitary granules maintains a spherical shape for a time and soon "disappears" after release.

These morphologic findings on granule genesis and release have some broader implications and more dynamic aspects. Among those already discussed by Palade are: the extensive and continuous circulation of membranous material between the surface and the interior of the cell that can be inferred; the method of compartmentalizing secretory products within the cytoplasm; and the suggestion of similarity between Golgi and cell membranes. Since granule size and form seems to be rather characteristic for a given cell type of the anterior lobe, we can also assume that the Golgi system determines the arrangement and limits the size of the emerging packet. Finally, on the basis of indications that the dense granule content is lost from view shortly after discharge, we can speculate that the environment of the connective tissue ground substance (already known to be influenced by a variety of agents, including hormones and enzymes) could affect the solubilization of hormonal products and their transfer from the cell to the circulation.

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THE ORIGIN OF PROTEIN YOLK FROM THE GOLGI APPARATUS IN GASTROPODS*

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The protein or albuminous yolk of gastropods arises not only during ovogenesis but also during embryonic development. Protein yolk is not something that is laid down during the growth period of the ovocyte gradually to disappear during the course of development. Instead, this protein material evidently exists in a dynamic state. In the yolk-containing or vegetal cells, it is continually being broken down during development, with a surplus of breakdown products continually being rebuilt into secondary protein yolk spheres. The animal cells during the cleavage stages do not possess protein yolk but develop this material during the larval period.

The morphology of this process, in which the Golgi apparatus is the obvious cellular component involved, was described in detail by Worley and Worley in 1943 (FIGURE 1*a*) and subsequently reviewed in 1946. By means of vital staining with methylene blue, they observed continually, over a period of several days, the giant gastropod Golgi bodies in cells of living tectibranch embryos. Consequently Worley and Worley were able to describe the activity of the Golgi material during the entire cycle of protein yolk elaboration.

Unfortunately, however, since the neutral red controversy of the late 1920s, conclusions drawn from studies made with vital dyes have not gained general acceptance among cytologists. Because of the well-known tendency of vital stains to produce artifacts in the cell, this attitude is partly warranted. Nevertheless, studies in cytoplasmic cytology involving the Golgi apparatus require a coincidence in findings, or a reasonable explanation of discrepancies, between vitally stained living material and unstained living material observed by phase-contrast microscopy, as well as material fixed both by the classic methods of the light microscope cytologists and the more modern techniques of the electron microscopists. It should be clear that a correspondence in the observations obtained by these various methods is a minimal prerequisite to a universally acceptable view of Golgi structure and function.

For these reasons the senior author's earlier studies with vital stains have now been supplemented with an investigation of yolk formation in gastropods by means of electron microscopy. In addition, some higher resolution electron micrographs were required to clarify some of the observations.

The arched slipper-shelled gastropod, *Crepidula fornicata* (L.), pro-

* This article, illustrated with slides, was the third of three papers presented at a meeting of the Section on January 9, 1961.

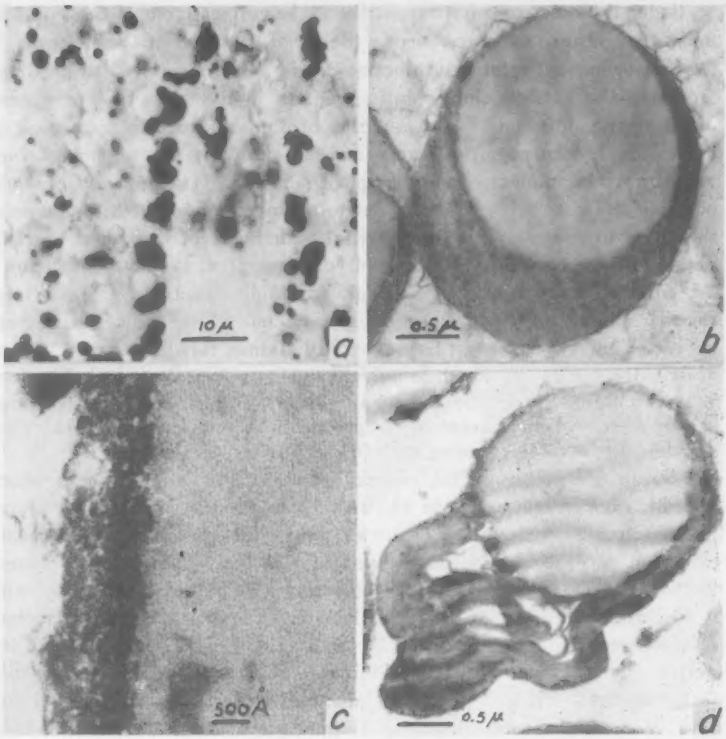

FIGURE 1. (*a*) Protein yolk (pale spheres) discharged from the Golgi material (dark) in the living *Navanax* veliger larva as revealed by vital staining with methylene blue (×950). Reproduced by permission of *Journal of Morphology*. (*b*) Electron micrograph of duplex Golgi vesicle before discharge of the protein yolk showing the relatively electron-dense cortex and the less dense core. Note that the cortex has a somewhat fibrous, inhomogeneous appearance, the core showing no fine structure at this magnification (×19,000). (*c*) High resolution electron micrograph showing the small regions of the cortex in which lamellations with a periodicity of about 45 Å can be discerned. The crystalline appearance of the protein core, periodicity about 70 Å, is evident (×120,000). (*d*) An intermediate stage in the withdrawal of the electron-dense cortex from the core (×19,000).

vided the material for electron microscopy. The results described here involve the veliger larva, the stage in development most significant in the elaboration of secondary protein yolk spheres. The full cycle of Golgi body activity, as described for the tectibranch *Navanax* (1943), has not yet been elucidated by means of electron micrographs of *Crepidula*. However, several of the most important stages have been identified and will be described here.

Under the electron microscope, the early veliger larva of *Crepidula* is seen to contain, scattered among the other cytoplasmic components, a few homogeneous, relatively electron-dense spheres referred to as Golgi droplets. Comparable chromophilic droplets in living tectibranchs were found to transform into Golgi vesicles of duplex structure consisting of an external, chromophilic cortex and an internal, chromophobic core. FIGURE 1*b* is an electron micrograph of such a Golgi vesicle in *Crepidula* showing the cortex, which turns out to be relatively electron-dense, and the inner less dense core. The partial withdrawal of the cortex from the core, the next stage in the process of yolk formation, is shown in FIGURE 1*d*. After withdrawal has been completed, each pyknotic cortex, or Golgi remnant, is seen to lie immediately adjacent to the now mature yolk sphere. This was shown in living, vitally stained larvae (FIGURE 1*a*), and is equally evident by electron microscopy (FIGURES 2*a* and *c*). The form of the collapsed pyknotic body may be nearly spherical with separated layers to form several internal compartments as shown here, or may show varying degrees of flattening with few or no compartments.

The finer structure of the cortical region of the Golgi vesicle, which appeared somewhat fibrous in FIGURE 1*b*, is evident in the higher resolution electron micrograph (FIGURE 1*c*). This structure is obviously made up of small regions composed of relatively short, denser layers separated by less dense layers, suggesting a degree of lamellation with a periodicity of about 45 Å (note also the apparent crystalline structure of the protein yolk core, periodicity about 70 Å). This lamellation of the cortex is much more highly organized and extensive in the pyknotic Golgi remnant (FIGURE 2*c*). This electron micrograph is of a small portion of such a remnant showing distinctly its lamellated nature. Note also the lamellated strand that still remains attached to the released protein yolk core. FIGURE 2*b* is a highly magnified view of the pyknotic Golgi remnant showing the lamellae that have a periodicity estimated at 40 Å.

No clearer evidence of the participation of the Golgi apparatus has been described. Here the active Golgi material completely encloses the prospective cell product throughout the course of its development, eventually releasing the product. In this it parallels the well-known and widely accepted cases of the participation of the Golgi apparatus (acroblast) in the formation of the acrosome during spermatogenesis.

The electron micrographs of the Golgi apparatus of these larvae seem to bear little resemblance to the structures now being identified as the Golgi apparatus by electron microscopists. However, it is becoming increasingly apparent that there is greater variety in the form of this cell organelle than originally anticipated. The significance of these variations and of the multilamellar structures and "whorled" bodies being reported in a variety of cells is not yet clear. No doubt it is a reflection, at least in part, of the nature of the material being synthesized. Such

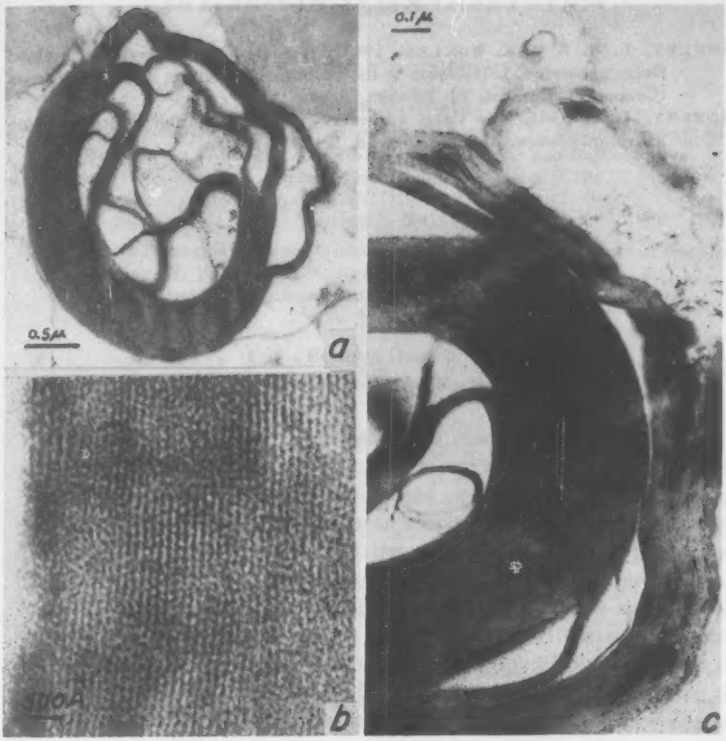

FIGURE 2.(*a*) After withdrawal is completed, the pyknotic cortex, or Golgi remnant, lies adjacent to the spherical yolk platelet. Compare with FIGURE 1*a* (×19,000). (*b*) A highly magnified view of the pyknotic Golgi remnant showing the lamellations, periodicity about 40 Å (×350,000). (*c*) A high resolution electron micrograph of a part of a Golgi remnant. Its lamellated nature is evident, particularly in the upper left and lower right portions of the photograph. A lamellated strand remains attached to the protein yolk core, upper right (×60,000).

variety in the appearance of the Golgi apparatus plus the well-known lability of the Golgi material dictates great care in interpretation, whether the study be of living material by vital staining, or of fixed material by electron microscopy.

Acknowledgments

The technical aspects of this study were carried out by Betty Hershenov of our biological laboratories whose patient and skillful devotion to this task is gratefully acknowledged. We are also grateful to Bernard Tandler of the Sloan-Kettering Institute for the photographs used in FIGURES 1*c*, 2*b* and *c*.

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DIVISION OF INSTRUMENTATION

SOLID STATE DOSIMETRY*

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Light is radiant energy produced by an electronic process emitted in quanta and transmitted by electromagnetic waves. Its origin is electronic since its source is the transition between energy levels of the outermost or valence electrons of an atom or an electron in a bound excited state. The ground state corresponds to the electrons occupying the lowest lying of a number of possible energy states. If one or more electrons were to receive energy, they would be raised to a higher energy level. When the electron is raised to an excited state it will attempt to return to a lower energy state by losing energy through radiation emitted in the form of an electromagnetic wave. The emitted energy, depending on the frequency of the "vibrating" electron, upon striking the eye may produce the sensation of light. Or the electromagnetic wave may be assigned to the ultraviolet or infrared region of the spectrum. An excited, single isolated electron may be considered as undamped linear oscillator. Upon returning to the ground state, the electron will emit an electromagnetic wave having a wave length specified by the frequency of the source. If this electron is no longer isolated but is located in the electronic or atomic environment of matter it will no longer be an undamped oscillator. The presence of the surrounding electrons will exert a damping force upon the electronic oscillator that will shift the frequency of the oscillator and hence the wave length of the emitted electromagnetic wave. If an electron migrates from one region of a solid to another, the electrical environment may differ and so will the damping. Under these conditions, after a migratory electron has been excited and attempts to return to ground state, it may now emit light in its new environment when it did

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not do so in its original position. Or if it did emit light in its original position, after migration it may emit light of a different wave length or emit no light.

These multiple effects take place in the phenomenon of luminescence which is the underlying principle of radiophotoluminescent and thermoluminescent implant dosimeters. In the radiophotoluminescent glass, exposure to ionizing radiation produces mobile photoelectrons. Some electrons are trapped in regions of structural defect to become, upon excitation with ultraviolet light, luminescent centers emitting orange-yellow light. The processes taking place are: (1) ionization of the constitutents of the glass, (2) production of photoelectrons, (3) migration of electrons, (4) recombination, (5) trapping of some electrons, (6) alteration in optical properties, and (7) emission of light upon ultraviolet excitation.

Thermoluminescent materials behave similarly. Only the excitation mode, excitation response, and trapping differ. Trapping does occur, but trap depth is shallow compared with trap depths in the radiophotoluminescent glass. Light emission is produced by heating, and the emitted light lies in the blue-green region of the spectrum.

Most of these physical effects have been described previously.[1-3] A few still require explanation before the theoretical discussion can be brought to a satisfactory conclusion. Exposure to ionizing radiation can produce changes in the optical properties of solids, specifically in luminescence, that is, the emission of light due to any cause except temperature. There are many forms of luminescence: bioluminescence, chemiluminescence, galvanoluminescence, triboluminescence, thermoluminescence, and radiophotoluminescence. The last three play a role in existing dosimetry systems.

A material may become luminescent when stimulated by suitable exciting radiation. If light emission ceases when the stimulant is removed, fluorescence has occurred. If emission persists after stimulation stops, the luminescence is designated phosphorescence. Thermoluminescent materials after stimulation become luminescent upon being raised to a higher temperature. Radiophotoluminescent materials exhibit luminescence poststimulation when they are subjected to ultraviolet radiation. Both thermoluminescent and radiophotoluminescent materials are storage phosphors, that is, phosphorescence is "frozen in" either permanently or temporarily after stimulation. A stimulant other than the original is required to release the "stored" phosphorescence.

It is suggested that the capital letters RPL be used as an abbreviation for radiophotoluminescence. This notation is similar to that used for thermoluminescence, TL. When an electron is stripped from an atom during irradiation of a solid, it may migrate through the solid until it is "trapped" by some constituent or by some region of the solid containing a structural defect. A "center" consisting of an electron and its trapping site has

optical properties different from the normal crystal or glass. For instance, it may emit fluorescent light under conditions where the unaltered solid would not do so. The radiation-induced changes may be detected by optical means and are a measure of radiation exposure. Since the effect in both TL and RPL materials is cumulative, such devices are integrators of radiation exposure or dosimeters. TL and RPL* dosimeters, like most solid-state inorganic dosimeters, are energy-dependent due to the "high" atomic numbers of the constituents. Proper shielding of these dosimeters is a must if they are to become truly useful instruments.

If an electron is tightly bound in a center (deep trap), the center is stable. In a shallow trap where binding is weak, the electron may escape from the trap and return to a proper location in the solid. If the traps are very deep, the electron may never be liberated even by an exciting agent. In this case, the effect is permanent and cannot be altered except by physical destruction of the solid, such as melting the glass. The RPL dosimeter falls in this category. Its record is permanent. The intensity of luminescence is directly proportional to the number of centers and so is a measure of dose.

If the trap is not shallow, "fading" or loss of centers will not occur at room temperature. However, excitation may liberate the electrons from their traps not only producing luminescence but also destroying the trap. In such a material, the exposure indication is erased by the act of reading and a reuseable dosimeter results. The TL dosimeter is an example of this type.

In TL materials, luminescence takes place when electrons leave the trap and return to "normal" positions. In a TL device, luminescence appears as the temperature of the device is increased and reaches a maximum at the temperature at which electron liberation is a maximum. Luminescent intensity then decreases and fades as the store of electrons is emptied. A plot of luminescent intensity versus time is a glow curve. A glow curve will have one peak if only one type of trap is present and many if multiple trap types are to be found. The area under the glow curve is the intensity sum of light produced by liberated electrons returning to their ground state. This area is a measure of total radiation exposure. If it can be measured and compared to various areas produced by different levels of ionizing radiation exposures, calibration can be achieved and a relative dosimetry system emerges. The glow curve may be traced by using a chart recorder, or an integrating circuit may be used. The latter approach is the basis for a TL dosimetry system using CaF_2:Mn.[2] This system promises to be more sensitive than the RPL glass needle. Its range may extend from 0.01 mr to 100,000 r. This low level of sensitivity presents problems: (1) it may be difficult to detect weak signals, (2) the

* A CaF_2: Mn RPL dosimeter was developed by J. Schulman *et al.* of the Naval Research Laboratory, Washington, D. C.

glass envelope containing the phosphor must not unduly attenuate the luminescence, (3) triboluminescence produced by normal vibration may produce erroneous signals, and (4) fading may be a factor at either room or body temperature.

If the foregoing factors can be overcome or are proved nonexistent, a highly sensitive dosimeter, possibly smaller than the glass needle, will result. Its sensitivity and reusability are unique characteristics.

The average "Z" of the RPL needle and CaF_2:Mn phosphor are approximately the same (H. Attix, private communication.) Tests of both when unshielded show similar energy response and confirm the similarity in average atomic number. This fact raises the possibility that the perforated, fine gold shield designed for the low Z RPL glass needle may be applied to the TL CaF_2:Mn phosphor to eliminate its energy dependence.

Physically the TL dosimeter resembles the RPL[21] dosimeter. The CaF_2:Mn powder will be contained within a sealed glass envelope not in a glass matrix. The moisture-free phosphor will be sealed in glass under a vacuum of 10^{-5} mm. of Hg. The powder will either be "loose" or sprinkled upon a graphite electrode. Stimulation will be produced in the latter geometry by passing a current through the graphite to heat the phosphor. In the former case, the entire assembly will be heated by placing it upon a suitable heat source. RF heating is also a possible mode. The TL system's medical capability is currently under investigation.

Two forms of the microdosimeter have been investigated. These were the type containing barium, potassium, and aluminum metaphosphate and a low Z glass containing lithium and magnesium metaphosphate instead of barium and potassium metaphosphate, with 8 per cent silver metaphosphate added to each system.* Since some of the elements employed in the regular composition glass are of relatively high atomic number, the glass is highly absorbent for low-energy X rays, rendering it more sensitive to these radiations than to harder radiations such as cobalt-60. The unshielded glass is energy dependent.

Work with the microdosimeter of regular and low Z composition glass has resulted in a gold shield having a wall thickness of 17 mils for the regular composition glass and 10 mils for the low Z glass.[4-9]

Since the RPL glass needle dosimeter is energy-dependent and a relative device, proper calibration is essential. The calibration must reflect the various radiation environments to which the needle will be subjected. The procedure is straightforward.

At least five groups of ten regular and low atomic number needles are selected. Predose is determined. Any malfunctioning needle is rejected. Each needle is placed within a gold shield. Regular and low Z composi-

*Both forms of the glass are available from the Bausch & Lomb Optical Co. Rochester, N. Y.

tion needles were then exposed to different X- or gamma-ray fields selected from these possible combinations (TABLE 1).

TABLE 1

Radiation source	Location in phantom
260 KVP X rays	Surface to D_{20}
1 MEV X rays	Surface to D_{20}
Co^{60}	Surface to D_{20}
Ir^{192}	1 cm. to 5 cm.
Radium	1 cm. to 5 cm.
Filtration (X rays only)	**HVL**
260 KV Thoreaus	2.5 cu
260 KV 1 mm. Al +0.5 mm. Cu	1.5 cu
1 MV 1 mm. Pb	3.9 Pb

The TSD is 50 cm., and the SSD is 55 cm. The groups chosen must select extreme radiation environments. Each group is exposed to the same dose. Exposure is determined from tables developed using NBS calibrated r-meters. Each r-meter has its wall thickness matched to the radiation environment. This procedure is *not* a comparison against Co^{60} radiation; it reflects all radiation energies present.

Each needle is read three times four hours and one day postexposure. Readings of any single needle are not successive. The needle is removed and reread. The predose is subtracted from the gross reading to obtain the net reading. Net readings are averaged for each group and the standard deviation taken.

Generally, individual readings will not deviate from the average by a factor equal to 50 per cent of the standard deviation. The averages for all groups are now averaged. This average is the calibration factor having the dimensions r/ua. It reflects the response of the shielded needle to different energies as found in the various environments. When this value is properly attained, needle accuracy is ±7 per cent or better.

The regular composition glass, as mentioned previously, is quite energy-dependent especially at the lower X-ray energies. The bare glass saturates at 1000 to 1300 r at 100 Kev. However, the low Z glass has been shown to be quite linear with effective X-ray energies of 75 Kev with radiation doses up to 2500 r. The apparatus used was a 120 kv mobile unit (3 mm. Al. filter HVI 3.5 mm. Al.).

There are two types of readers, one developed by the Bausch & Lomb Optical Company and the other by the United States Naval Research Laboratory, Washington, D.C. We have been employing the latter and have found that with certain modifications this model is satisfactory.[10] Regardless of which unit is obtained, it is necessary that a calibration be made so that a maximum range of at least 10,000 r be available for clinical or experimental use.

FIGURES 1 to 4 indicate the basic block diagrams that can be employed. The choice of the 3S4s in the reader is not accidental. This tube is excellent for low signals and low noise applications, which is the nature of the signal from the photomultiplier tube. One of the conditions to obtain this type of operation is the use of battery supplied voltages. To use A.C. voltages for the filament and rectified D.C. voltage for the plate voltage would introduce A.C. signal into the system. Since the input is a D.C. signal, any type of A.C. signal is unwanted and is considered noise. In order to keep noise to a minimum, battery supplied voltages are used throughout the entire reader.

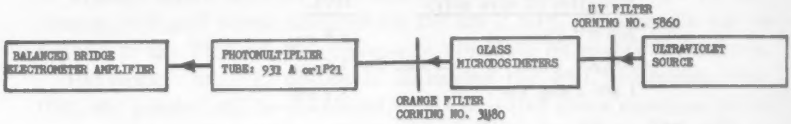


FIGURE 1. Basic block diagram of the "electronic read-out" unit of the fluorimeter.

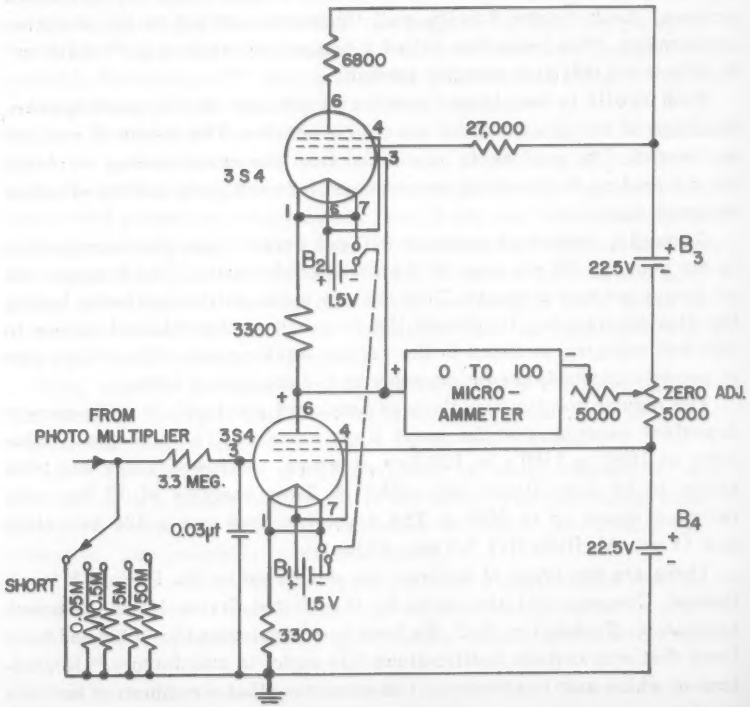


FIGURE 2. Four-position balance bridge electrometer.

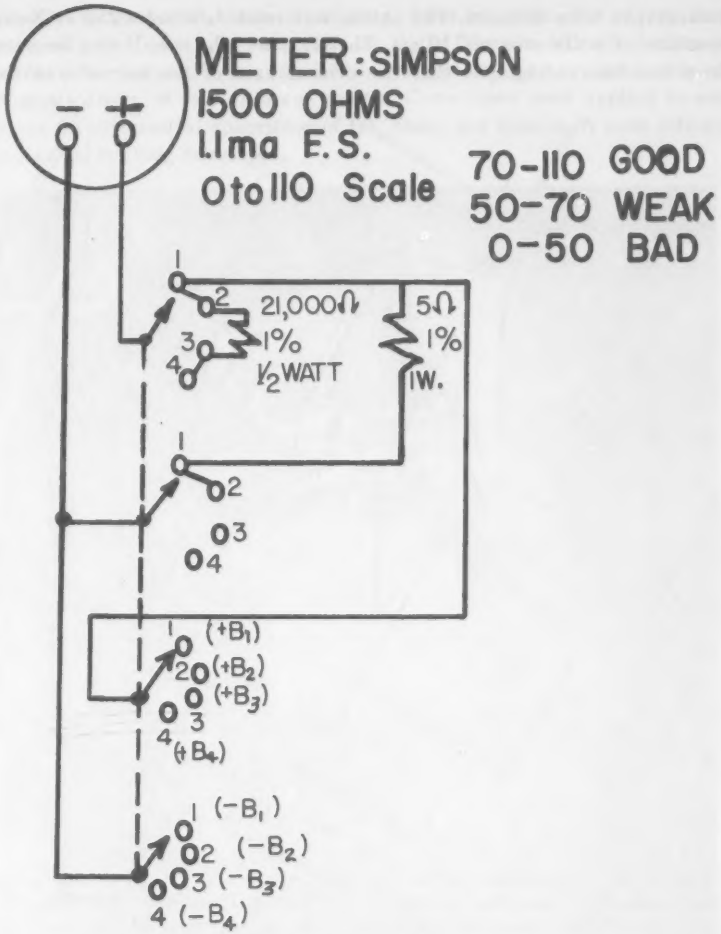


FIGURE 3. Circuit for battery check of amplifier.

The fact that the filament and the cathode are common in the 3S4s necessitates the isolation of the filaments from each other. To supply the voltages to the filaments from a common source would destroy the bridge arrangement in its present configuration.

A study still in progress at Brookhaven National Laboratory deals with multiple implant dosimetry and employs 150 shielded low Z dosimeters implanted at various levels into a dog weighing 38 lb. The animal was sacrificed prior to implant and embalmed. Plastic spacers were used to maintain proper distances within the nylon tubing and diagnostic

radiographs were obtained. The animal was rotated, using a 250 kv X-ray machine at a distance of 110 cm. The HVL was 2.3 cm. It may be seen from the two radiographs that the central axis of the animal was not

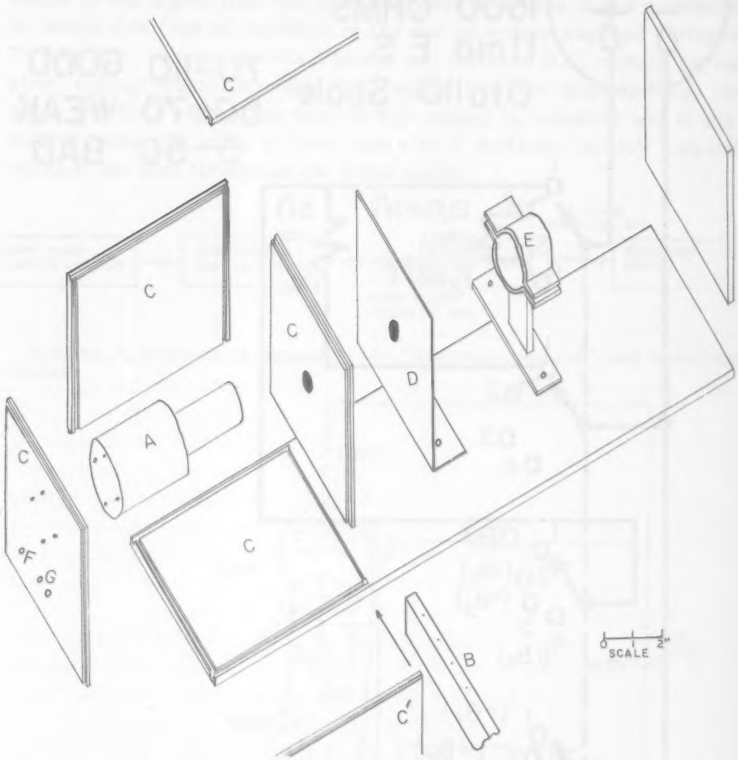


FIGURE 4. Exploded view of main parts of the reader system; high voltage and electrometer amplifier not shown. (A) Enclosed photomultiplier assembly, side window photomultiplier tube faces down in assembly. (B) Microdosimeter holder; one side of holder (facing UV light source) cut so that the UV exciting light may strike the long axis of glass dosimeter. (C) Face plates enclosing photomultiplier. Units are dovetailed to reduce light leakage. (C^1) Side plate into which unit B must pass through before coming into contact with A: dentents not shown, but should be included for accurate positioning of each dosimeter position. (D) Plate with aperature before C (with aperature) not shown is mechanical slit to cut-off the UV: when unit is warming-up. (E) Holder for UV lamp transformer (220V) not shown but mounted directly behind transformer. (F) High voltage input for photomultiplier assembly. (G) Photomultiplier current output, to balanced bridge electrometer.

Note: An industrial "maggy-fan" is required to cool UV lamp. This fan is normally placed so that the area between face-place C (with aperature) and plate D has the air directed to it.

exactly located at the axis of rotation. After exposure, the animal was autopsied and notations were made as to the location of each dosimeter within the anatomy.[11] FIGURES 5 and 6 indicate two separate acts of readings taken at two different depths. Corrections were applied to account for differential absorption of fat, bone, and muscle. A more refined procedure is being developed.

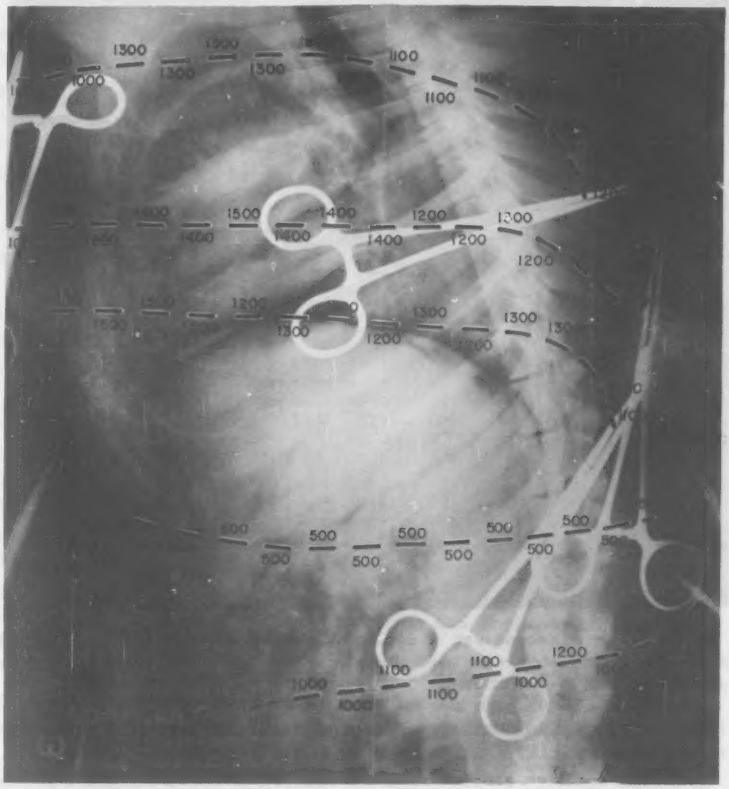


FIGURE 5. Gold-shielded dosimeters in dog. Forceps not used during radiation exposure.

The light weight of either dosimeter makes it a candidate for use in space-radiation research. In an area where instrument weight is at a premium, any dosimeter so light that 32,400 would weigh a pound should be given serious consideration. Even with metallic shielding, unit weight would only be increased to 0.29 gm. Either the dosimeter must be recovered or read in orbit. In the former case, weight is minimized. In the

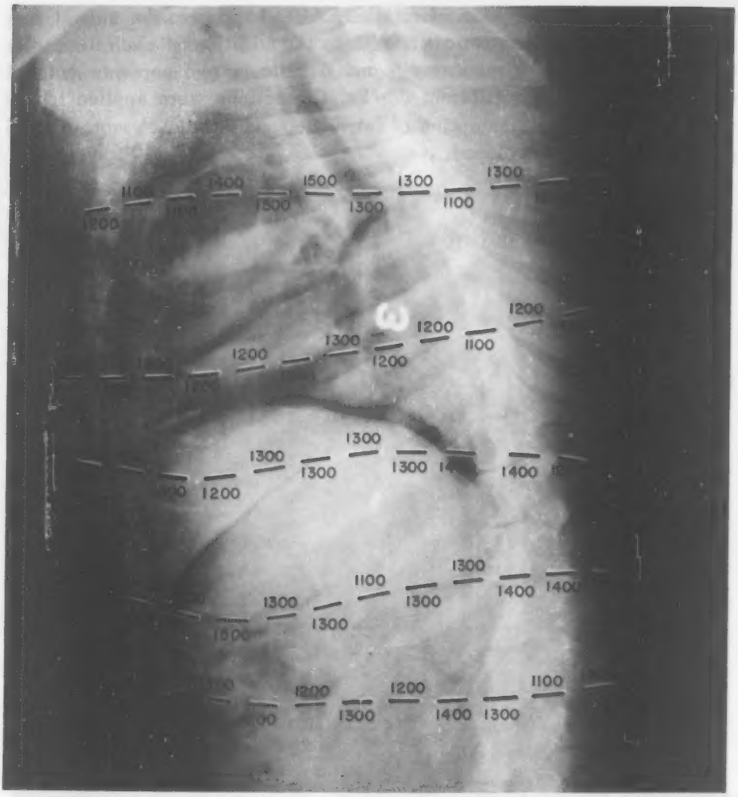


FIGURE 6. A second set of implanted glass dosimeters with gold shield. Each set of dosimeters were implanted at specific depths, removed a second implant performed, then irradiated.

latter event, a miniaturized reader and dosimeter transport mechanism must be designed.

With good design a space reader's weight and power demand could be held to acceptable limits. Both the RPL and presumably the TL dosimeters will respond to betas, neutrons, gamma rays, protons and Bremsstrahlung. These radiations are either present in space or are produced by the interaction of the space radiation environment with the vehicle skin and contents. These dosimeters provide an integral not a differential reading with respect to radiation source. Since they are not tissue equivalent or exhibit uniform response to different types of radiation, the reading would have to be carefully analysed with the aid of other data. For example, each needle should be subjected to gamma spectroscopy to

check for activation by charged or uncharged particles as well as high energy photons. If possible, selected threshold radioactivants should accompany a set of differentially shielded dosimeters. The combination of data derived from these detectors plus readings of differentially shielded needles should yield meaningful data. The needles could be implanted not only in differential phantoms but also in animals.

The dimensions of the glass needle are one of its outstanding properties. This fact led to the investigation of the needle's ability to detect the gamma component of a simultaneously delivered neutron-gamma exposure. Three approaches have been suggested.[12-15] Two of these rely on exposing an unshielded dosimeter to the mixed neutron gamma field thereby retaining desirable dimensional qualities. The third approach,[13] while undoubtedly feasible, detracts from the dimensional qualities, since it calls for use of a neutron shield comprised of enriched Li.[6] The stated wall thickness of the lithium shield are such that, if employed, the shielded dosimeter could not be inserted in a Number-8 French catheter.

The method proposed by the authors differs from Kondo's in that a knowledge of the neutron environment is needed. Since such information is essential for complete data analysis and is easily obtained,[16 17] this approach has been followed.

Neutrons produce ionization in an indirect manner. The neutrons must interact with a nucleus to produce an excited nucleus. The radiation, particularly beta rays, emitted by the radioactive nucleus produces ionization. If the neutron spectrum, needle composition, and cross sections of the needles constituents are known, the neutron-induced activation can be computed. It is then possible to compute the energy deposition in the glass needle due to the absorption of the radiation emitted by the radionuclei. Due to the small dimensions of a needle, it is reasonable to assume only beta rays undergo absorption and contribute to the energy absorption.

Use of the regular composition glass is indicated whenever neutrons are present. Regular glass contains barium and not lithium. This composition results in two favorable properties. First, the presence of lithium, a neutron sink, is avoided. Not only would lithium increase neutron sensitivity through greater absorption but would produce greater energy deposition since lithium undergoes a thermal neutron interaction generating the highly ionizing alpha particle. Second, barium has a high cross section for pair production, thus increasing needle gamma or X-ray sensitivity in high-energy regions. Since high-energy neutron-capture gammas are always present to a very large degree in a reactor, the needle may be a more efficient detector for a group of gamma rays that comprise the principle component of the gamma dose. The technique is as follows. The energy absorption due to neutron activation is calculated and expressed in rads. This value, which is a function of the thermal and re-

sonance neutron NVT, when subtracted from the gross needle reading gives the gamma dose delivered to the needle.

The calculated value of the neutron component of the glass dose is based on these major assumptions: (1) only the absorption of the betas emitted by decaying radio-silver is primarily responsible for neutron-induced energy deposition in the needle; (2) neutron-capture gammas originating in the glass and silver-decay gammas do not significantly contribute to the photo luminescence; (3) the average beta energy is taken to be one third of the maximum beta energy; and (4) all betas emitted are absorbed completely in the glass.

The average weight of silver in a regular needle is 546 μg. The two isotopes of silver following radioactive capture give rise to three radioisotopes: 2.3 m Ag-108; 270d Ag-110m; and 24s Ag-110. These isotopes emit seven betas having maximum energies ranging from 0.087 Mev to 2.86 Mev. Beta abundance varies from three to 100 per cent. These isotopes decay to stable Pd.

At least four hours are permitted to elapse between exposure and reading of the photoluminescence in order to permit decay of temporarily active centers and the stabilization of the effect. In this time interval, Ag-108 and Ag-110 decay completely. The energy deposition due to these isotopes is given by:

$$ED_{108 \text{ or } 110} = N\sigma_{ACT}\,\phi E_\beta A\, w^{-1}\, 1.6 \times 10^{-14}$$

The calculation is carried out for both isotopes. In this formula ED = energy absorption in rads; N = number of target atoms; σ = activation cross section in barns; E_B = average beta energy in Mev; A = beta abundance in per cent; ϕ = neutron NVT in n/cm.^{2} w = needle weight in grams; t = time post exposure to reading; and λ = decay constant.

The ED as defined in 1 must be summed to include activation of both isotopes due to thermal and resonance neutron activation.

The value of ED_{110m} due to long-lived AG^{110} is also computed:

$$ED_{110m} = N\sigma_{ACT}\,\phi E_B A w^{-1} \lambda \int_o^t e^{-\lambda t}\, dt\, 1.6 \times 10^{-14}$$

In practice a plastic covered needle is placed in proximity to neutrons monitor(s) such as gold. Use of this technique may be shown by the following application: at the Brookhaven National Laboratories during an experiment (thermal NVT was 1.5×10^{13} n/cm.^{2} delivered during 700 MW-sec.). The resonance flux is not significant. The neutron-produced dose was:

rads from Ag^{108}	1996
rads from Ag^{110}	4
rads from Ag^{110m}	1224
Total	3224

The gamma dose was obtained by subtraction:

4180 gross needle reading
3224 neutron-produced energy deposition
956 rads – gamma exposure.

The response of the needle to high energy gammas is assumed to be energy independent. The high-energy response (1 to 20 Mev) is currently under experimental investigation.

The validity of the second and fourth assumption, upon which the value of the glass-energy absorption rests, must be tested. This is an analytical test and should be completed early in 1961. In addition, the average beta energy should be measured. If the gamma rays accompanying the neutrons are soft gammas, the unshielded needle may respond erroneously due to its energy dependence. This is not believed to be a factor at the Brookhaven National Laboratories, since the gammas incident upon the needle are neutron-capture gammas (most probable average energy is 4.95 Mev) that have penetrated a thick Bi shield.

This technique may permit, probably for the first time, the convenient measurement of gamma dose delivered to a detector located in a neutron-gamma field.

Both regular and low Z glass were used with three different types of shields to produce bremsstrahlung[18] as an indicator of radiation dose being delivered by a beta-emitting isotopes. Based on P^{32} and Y^{90} studies using 1 and 10-mil wall gold and 3-mil stainless steel shields, the regular glass plus 3-mil stainless steel have produced a linear curve for both of these isotopes. Further studies employing betatron electrons and several other isotopes of considerably varying average beta energy is planned. The investigators hope that by this method a dosimetry system for beta-emitting isotopes may be resolved.

Finally, the radiophotoluminescent glass dosimeter (regular composition and low Z glass) is being developed into a training aid for students of engineering, nuclear engineering, physics, chemistry, and biology. The levels of difficulty and course content will vary for each group, but with the rise of solid-state physics this new area of radiation dosimetery will introduce new concepts and experimental programs that heretofore have not been available on the college level with simple equipment of this type.

In radiation therapy of deep-seated cancer, there is a universal need for a radiation detector to measure dosage with accuracy and with ease in all body tissues and spaces. Especially is this so today when we command the means for more aggressive treatment with higher tumor dosage and greater risk to critical normal tissues. In many institutions and radiation clinics treatment plans have become more complex and more sophisticated, utilizing mixed radiation modalities such as low-

energy plus high-energy radiation, X-ray beams plus electron beams, telecurie therapy plus interstitial nuclear materials. Our primary objective is to check the cancer at every turn, without irrevocable damage to normal tissues. Accurate dosimetry thus becomes ever more difficult. The dosimeter's characteristics that are especially attractive from a medical viewpoint are: miniature size, unusual ruggedness, easy identification in the body and inertness in body tissues, and fluids. A previous discussion of the various characteristics have been included in this paper.

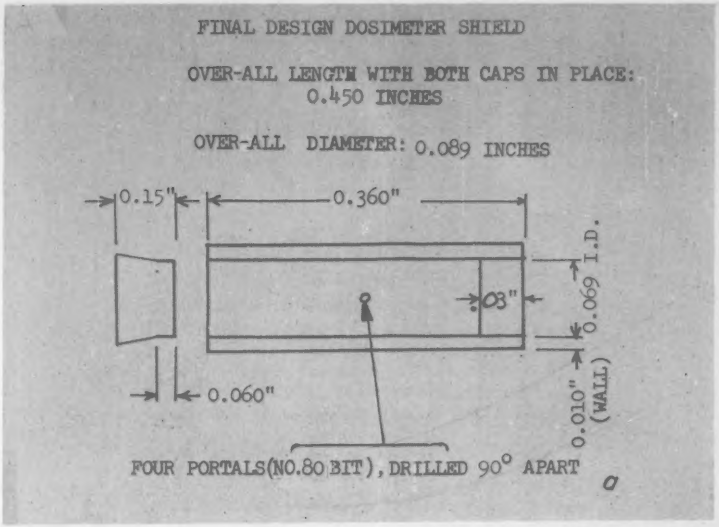
Multiple observations were made in many patients with a variety of malignant lesions including cancers of the larynx, tongue, kidney, stomach, brain, bladder, and in virtually every portion of the normal human anatomy. The microdosimeters were placed on the surface, in body cavities, interstitially, and in the major blood vessels.[19-20]

Special procedures have been devised for individual anatomical sites, but in general we have found that a common polyvinyl feeding catheter is an ideal conveyer to reach the kidney via the ureter (FIGURES 7 and 8) and also to reach the brain, and for most intravascular situations. A special catheter has been designed for the heart and for the small bowel. For the bladder, the Friedman-Lewis or Foley catheter has been utilized. During exploratory procedures for cancer, the dosimeters have been placed *in situ* in those individuals who will require postoperative radiation therapy. After the total given dose has been delivered, the dosimeter may be easily removed and read for the absorbed dose.

Our further investigations include total body dosimetry in cadavers and in living subjects receiving total body radiation. An area of prime interest will deal with the measurement of radiation in areas of varying body densities and geometries.

Conclusion

The dosimetry program described in this paper is an example of the benefits that can accrue to medicine when the necessary cooperation exists between the physicist and the radiologist. Each must recognize the responsibilities and competence of the other. The physicist must perceive the potential for clinical benefits that lie dormant in the precise recording of the physical phenomena of ionizing radiation. The radiologist must recognize the desirability for new instrumentation and help to develop the ideal modality for clinical use. This has happened in our experience. An intensive three-year program, carried out primarily on a part-time basis, is drawing to a close. During this phase the physicist have developed and demonstrated the medical feasibility and adaptability of radiophotoluminescent implant dosimetry. A useful instrument is now available for routine clinical application and has been turned over to the radiologist and the research worker for medical application.



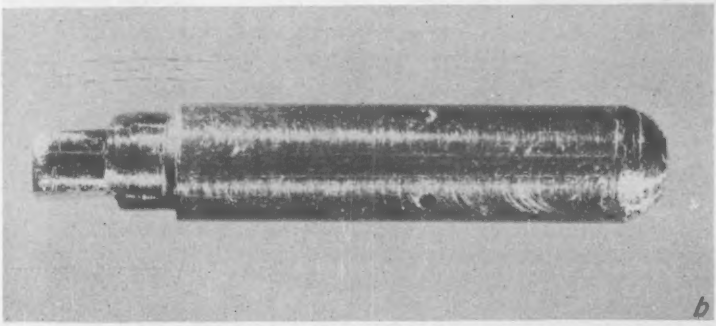


FIGURE 7(*a*) Dimensional drawing of dosimeter shield.

FIGURE 7(*b*) Assembled view of gold shield for glass dosimeter.

Acknowledgments

The work described herein could not have been accomplished without the encouragement or technical assistance of V. P. Bond, Dorothy Driscoll, Everett Heinze, James Gilmartin, Robert Dillingham and Edward Zeigler, all of the Brookhaven National Laboratories, C. B. Reid, Charles Spreckels, Louis Maddalone, Arthur Ammann and M. Pleasure of the United States

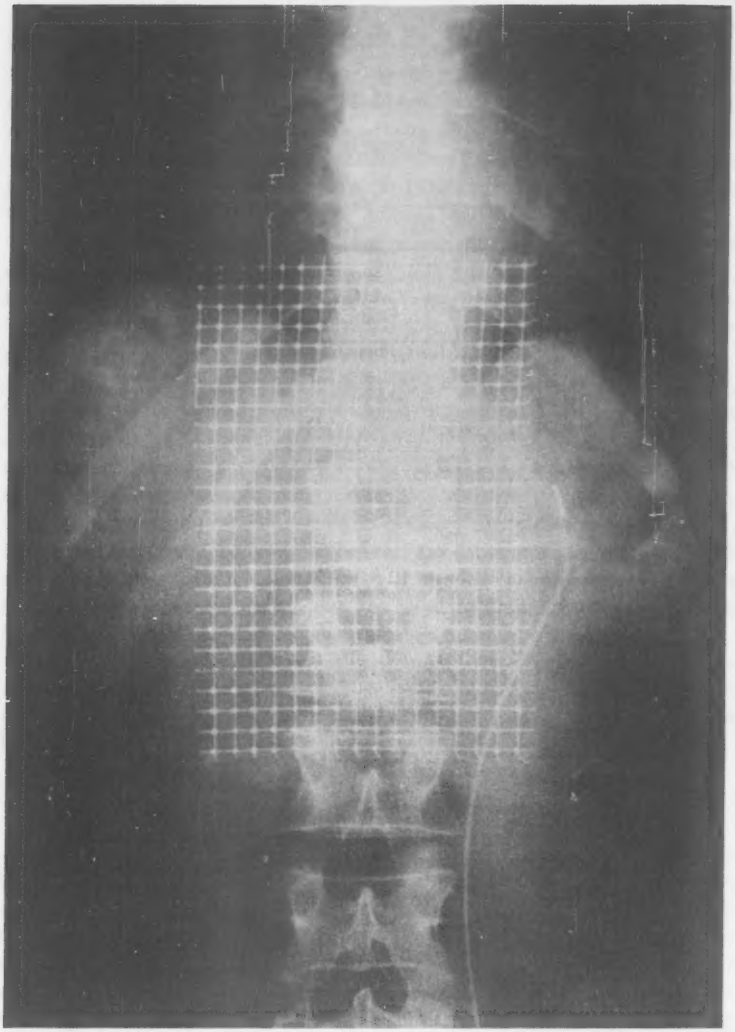


FIGURE 8. Illustrated here is the unique placement of the microdosimeter in the pelvis of the left kidney, utilizing a polyvinyl catheter directed up the left ureter. The metal grille represents the portal employed in irradiating this patient's retroperitoneal space for metastatic lymph nodes from cancer of the testicle. In such a setting it is imperative to know how much radiation the kidneys are receiving because their tolerance is sharply limited. Particularly is this important when high-energy radiation such as cobalt teletherapy is employed.

Veterans Administration Hospital, Bronx, N.Y., Jerome Saldick of American Machine and Foundry Atomics; John Boland and N. Hazelcorn of Mt. Sinai Hospital, New York, N. Y.; R. Goebel, professional engineer; and J. Schulman and H. Attix of the United States Naval Research Laboratories, Washington, D. C.

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SECTION OF PHYSICAL SCIENCES

THE MÖSSBAUER EFFECT: A PRECISION TOOL IN RELATIVITY AND IN SOLID-STATE AND NUCLEAR PHYSICS*

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The discovery of recoilless emission and reabsorption of nuclear gamma rays (the Mössbauer effect) has been one of the most exciting events in physics during the last few years. It has provided us with a powerful new tool with which—to mention some of its applications—to study the properties of the nucleus, to gain new insight into the nature of magnetism, to learn about the structure of crystals, and to test parts of the theory of relativity.

This paper is intended to give a broad, general picture of the significance, content, and applicability of Mössbauer's discovery. Primarily this article will be concerned with the work of others rather than with my own. For a more technical exposition the reader is referred to recent review articles[1,2] and to a bibliography of research papers written before June 1960.[3]

Nuclear Radiation as a Precision Clock

A precision clock in physics research must measure small departures from its own normal rate by comparing it with an identical clock. In this way quantitative information is obtained about the cause of the change. Electromagnetic radiation with its associated periodic properties has long been considered as a suitable candidate for a precision clock.

Consider, as an example, a pair of identical atoms. In one of them a valence electron has been excited to a level whose energy is E_0 above the ground state (FIGURE 1). The atom will return to the ground state by emitting a photon (perhaps of visible light) of energy E_0 and hence of frequency $\nu_0 = E_0/h$, where h is Planck's constant. The other atom, which is in the ground state, may absorb this radiation since it has just the right frequency to raise this atom to the excited state E_0. If for any reason the energy level spacings of either atom have been changed, or if something has happened to the frequency of the radiation in transit, reabsorption cannot take place. By restoring the absorption through the

*This paper was presented at a meeting of the Section on January 18, 1961. Its preparation was supported by the National Science Foundation, Washington, D. C. The work described in this article was done by others and supported by various agencies.

The Division of Psychology held a meeting on January 16, 1961, at which Goses Brožek of the Department of Psychology, Lehigh University, Bethlehem, Pa., presented a paper entitled "Soviet Research on Nutrition and Higher Nervous Activity." This paper will be published as an Annal of the Academy.

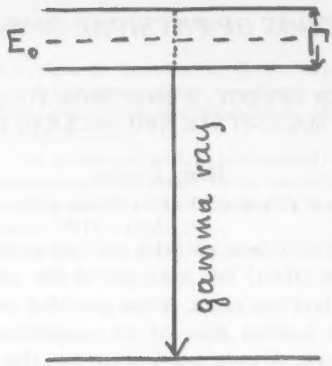

FIGURE 1. Energy level diagram of atom or nucleus, showing ground state and excited state of energy E_0 and uncertainty Γ.

addition of a known amount of energy from the outside, the perturbation that caused the frequency mismatch may be measured.

Atomic radiation is not an adequate tool for measuring very small frequency shifts. For one thing, many of these shifts arise from interactions in the nucleus and therefore affect only radiation that originates inside the nucleus. However, the small changes due to such external causes as the presence of a gravitational field also cannot be detected with atomic radiation. The reason is that the energy levels of an atom (or any other physical system) are not sharply defined. Instead, the energy E_0 of an excited state is undetermined by an amount Γ. Consequently the de-excitation radiation (for example, as seen in a spectroscope) will not be an infinitely sharp line, but will show instead a frequency spread $\Delta\nu = \Gamma/h$ about its central frequency ν_0. Typical numbers for atomic radiation are $\nu_0 = 5 \times 10^{14}$ cycles/sec., $\Delta\nu = 5 \times 10^{6}$ cycles/sec., so that the relative spread $\Delta\nu/\nu_0 = 10^{-8}$. Because of the broadening of both emission and absorption lines, a perfect frequency overlap is no longer necessary to produce substantial reabsorption. If, for example, the relative shift in the central frequency due to the effect under investigation $\Delta\nu(\text{exp})/\nu_0 = 10^{-15}$ (as it is for the gravitational shift), there is no hope of detecting the shift.

Now let us consider the situation for nuclei. The spacings of nuclear energy levels E_0 are about 100,000 times as large as those for electronic states. The line widths are, in the most favorable cases, about the same as those of atomic spectra. The ratio $\Delta\nu/\nu_0$ for nuclei may therefore be as small as 10^{-13}. Since a 1 per cent decrease in the overlap between emission and absorption lines can just about be detected, nuclear gamma radiation therefore seems suitable for the measurement of frequency changes of 1 part in 10^{15}.

Here, however, the laws of conservation of momentum and energy con-

spire against us. A gamma ray that has an energy E_0 automatically carries away a momentum $p = E_0/c$ (c is the velocity of light). The emitting nucleus must recoil with an equal and opposite momentum p, which in turn means that the nucleus acquires a kinetic energy $R = p^2/2M = E_0^2/2Mc^2$, where M is the mass of the nucleus. The full energy E_0 released in the nuclear transition therefore cannot have gone to the gamma ray; the latter will lack an amount R. An identical deficit would be incurred upon reabsorption. To see whether any reabsorption can occur at all, we must compare $2R$ with Γ (FIGURE 2). For a typical case $2R \approx 10^6\ \Gamma$ so that no overlap occurs at all.

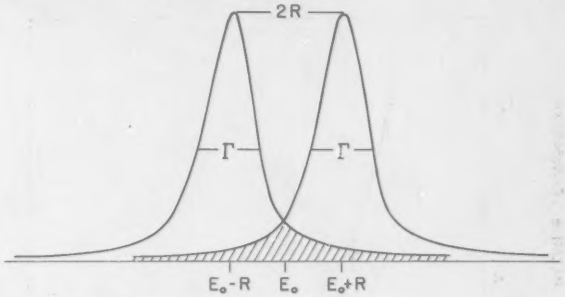

FIGURE 2. Overlap of emission and absorption curves when the nuclei receive a recoil energy R. E_0 is the energy of the excited state; Γ, its width.

There is a way out of this dilemma. The energy deficit can be made up from the outside. Suppose, for example, the emitting nuclei are attached to a rapidly moving disk so that they have a large velocity v in the direction of the observed gamma ray. The frequency of the gamma ray will then be raised, by the Doppler shift* $\Delta\nu = \nu v/c$. To make up the $2R$ energy deficit, the nuclei must be given mechanical velocities, typically, of about 300 m./sec. This can be done, but the measurement of a small experimental shift $\Delta\nu$ (exp) cannot be realized. For the mechanical velocity will surely not remain exactly constant, and even a very small variation (for example, 1 part in 10,000) will broaden the spread of the emission line to many times its barely tolerable natural width. Another method of restoring the condition for reabsorption is to heat the source and absorber to high temperatures, relying on Doppler shifts due to thermal motion. Since the thermal velocities are not at all sharply defined by the temperature, the lines are again for our purpose broadened beyond use.

Mössbauer's Discovery

In this context, let us describe Mössbauer's discovery.[4] Mössbauer measured the transmission of gamma rays from the 129 kev level in iri-

*This expression is correct to first order in v/c.

dium 191 through a crystalline natural iridium (38.5 Ir^{191}) absorber. The startling result was that in spite of the large expected recoil deficit, he obtained a small but significant amount of absorption without spinning the source or employing any other method to supply the missing energy. In fact, instead of heating the nuclei to a high temperature, Mössbauer achieved the effect by cooling the source and absorber to low temperatures. The results are shown in FIGURE 3. The rise in absorption with decreasing temperature must be interpreted as being caused by an increase in the fraction of source nuclei emitting gammas without recoil as the temperature is lowered.

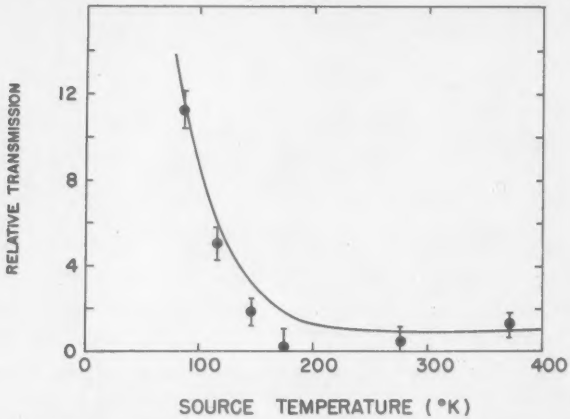

FIGURE 3. Dependence of the Mössbauer effect on temperature. Plotted is the relative absorption in Ir^{191} as a function of the temperature of the source. The points are Mössbauer's,[4] the solid curve is a theoretical fit by Visscher.[5]

The fact that the emission and absorption of a certain fraction of nuclei *was* recoilless is brought out by FIGURE 4. It shows the absorption obtained by Mössbauer when he mounted the source on a turntable that was rotated *slowly* to give the source nuclei a *small* relative velocity with respect to the absorber nuclei. Both the source and absorber were kept at 88° *K*. The absorption peak is centered at zero relative speed of the source with respect to the absorber, showing that for those gammas for which absorption occurred, there was no observable recoil loss whatever. The picture of recoilless emission and absorption is confirmed by the shape of the curve. Its width, when the abscissa is converted from velocity units to energy units, is just twice the natural width Γ of the 129 kev. level. This result may be shown to be exactly what is to be expected when a recoilless emission line of width Γ about $E_0+\Delta E$ (where ΔE is the externally introduced Doppler energy) is superimposed on a recoilless absorption line of width Γ about E_0.

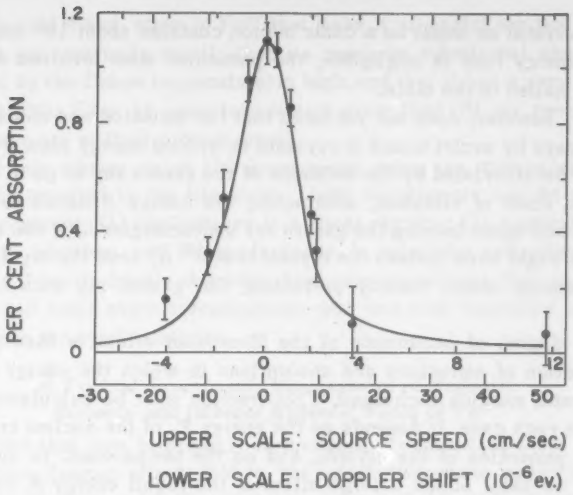

FIGURE 4. Recoilless absorption in Ir^{191} as a function of the relative velocity between source and absorber. The lower scale on the abscissa shows the Doppler energy that corresponds to the velocity on the upper scale. The points are Mössbauer's,[4] the solid curve is a theoretical fit by Visscher.[5]

The theoretical explanation[4-6] of the Mössbauer effect, based on a theory of Lamb[7] for neutrons, cannot be given here in any detail. We can discuss some qualitative features. The obvious feature of Mössbauer's experiments, which distinguishes them from experiments in which gases are used, is that the source and absorber nuclei are not free, but are bound in crystals. If the emitting and absorbing nuclei were rigidly nailed to, for example, a table, we should at once understand the absence of any measurable recoil energy. ($R = p^2/2M$, where now M would be the mass of the nucleus plus that of the table.)

Nuclei in crystals are not nailed to anything. They are arrayed, however, in a lattice that is vibrating. The allowed vibrational energies cannot assume continuous values but are quantized. The first important fact about these vibrational states is that the transition from one crystal state to another that may accompany the emission of a gamma ray by a particular nucleus cannot carry off any momentum. In a pictorial sense this can be understood by thinking of the nucleus in the lattice as vibrating rapidly back and forth. The linear momentum, a vector quantity, averages out to zero. Thus since no vibrational state has any momentum associated with it, a change in the vibrational state cannot involve any transfer of momentum. Conservation of momentum must, however, still be satisfied, which means that the crystal as a whole must recoil.* Since

*There are subtleties in this argument that have been discussed by Weisskopf[8].

even a crystal as small as a cubic micron contains about 10^{10} atoms, the recoil energy loss is negligible; the particular atom involved might as well be nailed to the table.

This, however, does not yet mean that the emission and absorption of gamma rays by nuclei bound in crystals is without energy loss. The crystal may be stimulated by the emission of the gamma ray to go to a higher quantum state of vibration, abstracting the energy it needs to do this from E_0 and again leaving the gamma ray underenergized. Or the emission process might even (unless the crystal is at 0° K) send the crystal into a lower energy state, thereby presenting the gamma ray with too much energy.

The degree of occurrence of the Mössbauer effect is then given by the fraction of emissions and absorptions in which the energy state of the crystal remains unchanged. This fraction must be calculated, in detail, for each case. It depends on the energy E_0 of the nuclear transition, on the properties of the crystal, and on the temperature. In qualitative terms, we shall obtain a large effect if the recoil energy R that a free nucleus would get is not larger than the maximum possible vibrational energy of the crystal and if the energy associated with the temperature is low compared to both of these.

Since Mössbauer's original discovery of the effect in Ir^{191} many other nuclides have been found that show a measurable amount of recoilless transitions. By far the most favorable one for research applications is iron 57. The decay scheme is shown in FIGURE 5. Some of the properties

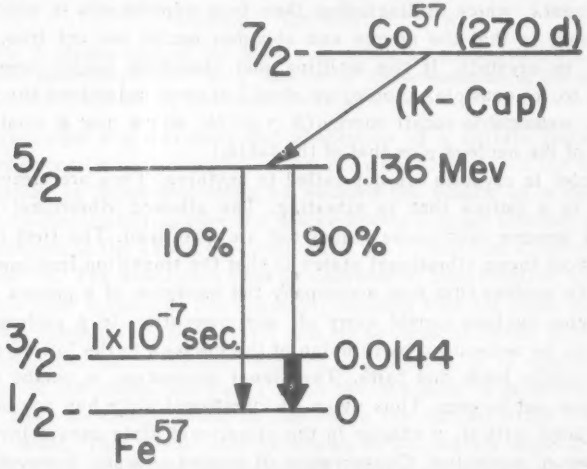

FIGURE 5. Decay scheme of Fe^{57}. The data to the left of the levels are their spins and parities, those to the right their energies. The times shown are the half lives.

of the E_0 = 14.4 kev. state in Fe^{57} that make it so useful are that E_0 and hence R are unusually small, that its maximum vibrational energy (as measured by the Debye temperature) is high, and that it has a very narrow natural width. Even at room temperature more than 70 per cent of the gamma rays are emitted without recoil.

As of this writing about 100 experiments using the Mössbauer effect have been reported in the literature. These experiments may be divided into three groups: (1) applications in nuclear physics; (2) applications in solid-state physics; and (3) applications in relativity and other basic problems. I shall briefly describe here one experiment that combined nuclear and solid state investigations and one that confirmed a basic tenet of the theory of relativity.

A Typical Experiment: Measurement of Magnetic Moments and Internal Magnetic Field of Fe^{57}

The fact that iron is strongly ferromagnetic means that there should be a nuclear Zeeman effect; that is, the interaction of the magnetic field due to the electrons with the magnetic moment of the nucleus results in a splitting of the nuclear energy levels and hence of the transition lines. A level whose spin is I and whose magnetic moment is μ will, in an internal magnetic field H, be split into $2I+1$ sublevels, separated in energy by $g = \mu H/I$. The ground state of Fe^{57} has spin ½ and the 14.4 kev. excited state has spin ³⁄₂. The split-level structure and the allowed transitions are shown in FIGURE 6.

The relative motion technique may be applied to measure the separations g_0 (ground state) and g_1 (excited state). At zero relative velocity between source and absorber the six emission components perfectly match the corresponding six absorption components, yielding maximum absorption, as if there had been no splitting. As the source is moved, the emission components all receive an additional (Doppler) energy and they cease to overlap with the components in the absorber. If now the velocity of the source is increased further, situations will arise in which the energies of some but not all emission and absorption components will again match. For example, if the Doppler energy increment of the source components is equal to g_1 the source gamma ray labeled 1 in FIGURE 6 will have the correct energy to excite transition 2 in the absorber; 2 will match 3, 4 will overlap 5, and 5 will have the right energy for transition 6. The gamma rays from the source corresponding to transitions 3 and 6 will not be resonantly absorbed. In this and similar ways 7 additional partial overlap situations are created when the source is being moved toward the observer.

The positions, as a function g_0 and g_1 of the centers of the reabsorption lines, as well as their relative intensities are shown in FIGURE 7 by vertical lines. Also shown on the same figure are the experimental

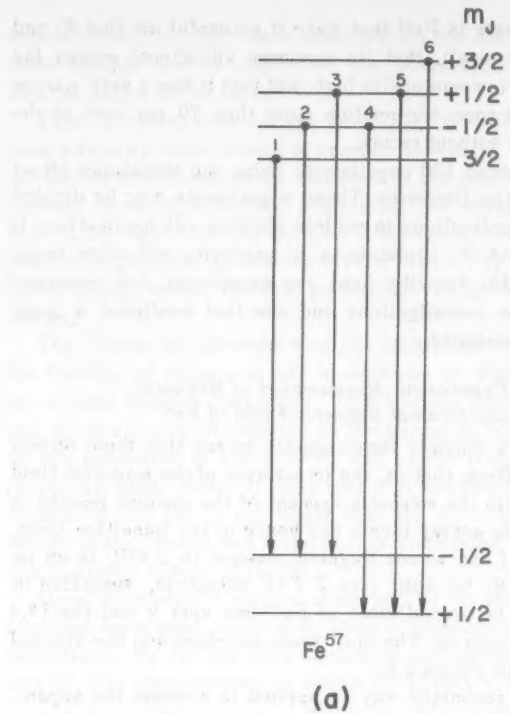

FIGURE 6. Zeeman splitting and transitions between the first excited and ground states of Fe^{57}, assuming magnetic dipole interaction and a negative magnetic moment of the excited state. The magnetic quantum numbers m_j are shown on the right.

results obtained at the Argonne National Laboratory, Lamont, Ill.[9,10] In the Argonne experiments, the absorber (a piece of rolled 76 per cent Fe^{57}, 0.1 ml. thick) was attached to the bed of a lathe and the source (an alloy of active Co^{57} and 99.91 per cent Fe^{56}, electroplated upon a strip of ordinary iron 0.5 ml thick) was fastened to the carriage of the lathe. The motion of the lathe, which was made automatic, was capable of providing uniform velocities of the source as small as 10 μ/sec. The detector of transmitted radiation (a 40 ml. sodium iodide crystal) was mounted on the axis determined by source and absorber. The excellent agreement of the experimentally observed transmission as a function of velocity with the superimposed theoretical predictions (for the assumed values of g_0 and g_1)* permitted the determination of g_0 and g_1. Together with a measurement elsewhere of μ_0, this yielded values for μ_1, and for

*Only 6 absorption pips were seen, instead of 8, because 2 pairs could not be resolved.

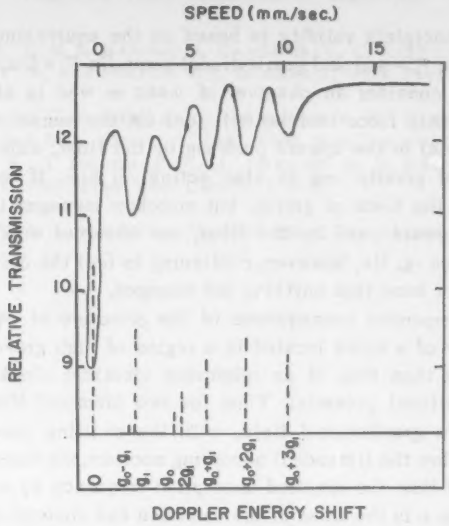

FIGURE 7. Mössbauer effect in Fe^{57} showing Zeeman splitting. The curve is the observed relative transmission as a function of the relative velocity between source and absorber. The dashed vertical lines indicate the positions and relative strengths of the absorption maxima for the chosen values of the splittings g_0 and g_1.[10]

H. The magnetic moments turned out to be unexpectedly small, a result of interest for the shell model of the nucleus. The internal magnetic field was found to be 333 ± 10 kilooersteds. Of even greater immediate importance than the magnitude of the magnetic field at the nucleus was the question whether this field would align itself parallel or antiparallel to an external magnetization. The question was answered by a subsequent Argonne experiment[11] in which a strong external aligning field was applied to the source. It was found that the Zeeman splittings were slightly reduced. This means that the applied and internal fields have opposite directions, an unexpected and important clue in efforts to understand the origin of the internal field.[12]

A Much Publicized Experiment: Measurement of the Gravitational Red Shift

The foundation stone of Einstein's General Theory of Relativity is the principle of equivalence. This principle states that an isolated observer cannot tell the difference between being in equilibrium under the combined actions of a gravitational field and an equal and opposite mechanical force, and between undergoing an acceleration due to the unopposed mechanical force in a region in which there is no gravitational

field. The principle's validity is based on the equivalence between inertial mass (in $F = ma$) and gravitational mass (in $F = Gm_1m_2/r^2$). Let us, for example, consider an observer of mass m who is standing on the ground. The only force that he will feel (in the sense of experiencing actual stresses) is the upward push mg by the floor, although the downward force of gravity $-mg$ is also acting on him. If we now secretly "turned off" the force of gravity but somehow managed to maintain unabated the upward push by the floor, our observer would ascend with an acceleration -g. He, however, continuing to feel the only force he ever felt, would not know that anything had changed.

It is an important consequence of the principle of equivalence that the frequency of a clock located in a region of high gravitational potential is lower than that of an otherwise identical clock situated at a lower gravitational potential. Thus for two identical Mössbauer nuclei in the earth's gravitational field, with the emitting nucleus located a distance l below the (intended) absorbing nucleus, the emission frequency will be lower than the required absorption frequency by an amount $\Delta\nu = \nu gl/c^2$ (where ν is the mean of the emission and absorption frequencies.)[1] If the emitted radiation were in the visible range, it would, from the viewpoint of an observer located at the position of the absorber, be shifted toward the red; hence the name "gravitational red shift."

If absorption is to take place, nevertheless, the frequency deficit must be made up by adding a shift in the other direction from the outside, for example, by the turn-table Doppler shift technique. The relative frequency shift $\Delta\nu/\nu = l \times 1.09 \times 10^{-16}$ (l in cm.), so that for an experiment which is to be carried out in an earthbound laboratory (l small) it is essential that $\Delta\nu/\nu$ due to the natural line width be also very small. Pound and Rebka[13] found that the 20 m. tower of the Jefferson Physical Laboratory at Harvard University, Cambridge, Mass. provided just a sufficient height to detect the gravitational red shift in Fe^{57}. For a description of this experiment, which required ingenuity and precision, the reader is referred to the original paper. The result was reassuring; it confirmed the principle of equivalence to a high degree of accuracy.

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DIVISION OF ANTHROPOLOGY

LÉVI-STRAUSS IN THE GARDEN OF EDEN: AN EXAMINATION OF SOME RECENT DEVELOPMENTS IN THE ANALYSIS OF MYTH*

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The study of myth has always had a central place in anthropological studies, but the views of anthropologists have varied greatly both on matters of definition and of interpretation. In this respect the celebrities of the past 80 years fall into 2 classes. First, there is a group of writers whom we may call *symbolists* – among whom I would class James G. Frazer, Sigmund Freud, and Ernst Cassirer in his earlier phase – who assume that the elements of myth are to be understood as symbols that are pieced together into a nonrational story much as in a fairy tale or dream. These writers hold that the "purpose" or "meaning" of myth is one of two kinds: (1) myth "explains the inexplicable," for example, the origin of the world, the origin of death; (2) myth is a kind of word magic that purports to alter the harsh facts of reality by manipulating symbolic representations of these facts.

Common to all the symbolist writers is the view that a myth can be understood as "a thing in itself" without any direct reference to the social context in which it is told; the meaning can be discovered from a consideration of the words alone.

The second group of writers are the functionalists – among whom I would class Emile Durkheim and his associates, Jane Harrison, B. Malinowski, and Cassirer in his later phase. The key theme here is the assumption of an intimate and direct association between myth and social action; the myth and its associated rite are held to be two aspects of the the same unitary whole.

The most explicit formulation of this doctrine was provided by Malinowski in his well known essay *Myth in Primitive Psychology* (Malinowski, 1926). Myth provides a "charter" or justification for facts in the present day social situation. For example, in the Trobriand myth of emergence, it

* This paper was presented at a joint meeting of the Division and the American Ethnological Society on January 23, 1961.

The Division of Biochemistry held a meeting on January 24, 1961, at which Maynard E. Pullman of the Public Health Research Institute, New York, N. Y., presented a paper entitled "Components of the Energy-Coupling Mechanism of Oxidative Phosphorylation." This paper will not be published by the Academy.

The Division of Microbiology held a meeting on January 27, 1961, at which Karl Maramorosch of the Boyce-Thompson Research Institute, Yonkers, N. Y., presented a paper entitled "The Mystery of Cadang-Cadang." This paper will be published as an Annal of the Academy.

is recorded that the brother and sister founder ancestors of each matrilineal subclan emerged from holes in the ground, the position of which is precisely recorded by tradition. Each ancestral hole is located in territory that is today regarded as the hereditary property of the subclan descendants of the original founder ancestors. Thus a tale that considered in isolation, has all the appearance of fantasy is seen to "make sense" when related to its social context. Within the framework of Trobriand ideas this myth has the force of a legal precedent in a court of law.

As C. Lévi-Strauss puts it: "This theory assumes that myth and rite are homologous ... the myth and the rite reproduce each other, the one at the level of action the other at the level of ideas." (Lévi-Strauss, 1956 p. 289).

It is a necessary corollary of this functionalist thesis that myth can be studied *only* within its social context. A myth divorced from its associated rite can have no meaning. Myth is never "a thing in itself."

British social anthropologists of my generation were brought up to believe that, on this issue, Malinowski was right. Detailed modifications of his original theory might be possible but the essentials of the argument were unassailable.

One consequence of this acceptance of the functionalist thesis has been that the collections of "literary myths" that exist in ethnographic libraries and in the sacred writings of the more sophisticated religions have come to be neglected by the professional anthropologist. Such myths, in the form in which we now have them, are clearly "divorced from their ritual context," hence, according to the functionalist dogma, they cease to be of interest.

The same line of reasoning eliminates from the field of serious academic discussion the whole of the works of Frazer and other exponents of the Frazerian "comparative method." Many of the comparisons to which Frazer draws our attention are very striking but, since Frazer consistently ignored the context of his evidence, it is a matter of functionalist dogma that we *must* ignore the apparent implications.

In a number of essays published over the last four years Lévi-Strauss has quite explicitly repudiated the functionalist thesis (the key document is Lévi-Strauss, 1955) in favor of a revised form of "symbolist" analysis that he calls structural. Lévi-Strauss denies the existence of any causal link by which myth overtly justifies the patterning of social action or vice versa. He concedes that myths and rites that occur in the same cultural environment may very well share a common structure. Hence if the elements of a myth or the elements of an associated rite are treated as the elements in a logical statement, the myth and the rite may appear to "say the same thing." Nevertheless, myth and rite are independent and each can be studied in isolation.

According to Lévi-Strauss the best method of ascertaining the "mean-

ing" of a myth is to assemble together all the variant forms in which it has been recorded regardless of their date or source. What we are looking for is the fundamental essence, and this essence, according to Lévi-Strauss, is a matter of logical structure that will persist throughout all the diversities of form by which the myth story has been perpetuated. A comparison of the different versions of a single myth complex will reveal this common structural nexus, and it is this common structure that really gives "meaning" and importance to those who recount the myth.

If we accept this view, then it follows that, despite anything that Malinowski may appear to have demonstrated, the social anthropologist is fully entitled to study myth as "a thing in itself" without regard to detailed consideration of social or ritual context. I do not ask anyone to suspend his critical judgement. Lévi-Strauss' thesis has many weaknesses and some of them seem a good deal more damaging than the alleged weaknesses of functionalism. Nevertheless, he has made out a case. At the very least he has demonstrated that the functionalist thesis, in its more orthodox form, is unnecessarily inhibiting. He has reopened what had begun to look like a closed argument. We need not accept Lévi-Strauss' views in every particular, but it is quite clear that the proper understanding of myth is once again a very open question.

As Lévi-Strauss himself recognizes, his new theory is exceedingly difficult to put to the test. In effect he postulates that the symbolic elements in a myth are analogous to neutral pebbles of diverse colors. One cannot discover what the elements "mean" by any straight forward technique of intuition or verbal interpretation; all that one can do is observe how the pebbles are grouped together into patterns. In principle, this patterning (or structure) of the symbols in relation to each other is a matter of statistics. Lévi-Strauss maintains that a really thorough application of the method would entail the use of punched cards and the services of an electronic computer (Lévi-Strauss, 1955). Since most of us operate under the delusion that some myths appear meaningful in a fairly straight forward way this kind of intellectual sophistication may arouse suspicion; nevertheless I suggest that the matter be given serious consideration.

If we accept Lévi-Strauss' view, the heart of the matter is that myth furnishes a "logical" model by means of which the human mind can evade unwelcome contradictions, such as that human beings cannot enjoy life without suffering death or that rules of incest (which specify that legitimate sex relations can only be between members of opposed kin groups) conflict with a doctrine of unilineal descent. The function of myth is to "mediate" such contradictions, to make them appear less final than they really are and thus more acceptable. This end is not served by isolated myths but by clusters of myths that are similar in some ways but different in others so that, in accumulation, they tend to blur the edges of real (but unwelcome) category distinctions.

Among the examples that Lévi-Strauss has used to illustrate his thesis are the following:

(1) He claims that an analysis of certain Pueblo Indian myths shows that the central problem that the myth cluster seeks to resolve is the opposition between life and death. In the myths we find a threefold category distinction: agriculture, hunting, and war. Agriculture is a means to life for man but entails the death of animals. It is thus a mediating middle category.

In another version of the same myth cluster a further threefold category distinction emerges: grass-eating animals, ravens, and predatory animals. Grass-eating animals are vegetarians; they need not kill in order to live. Ravens and predators are meat eaters; but ravens need not kill in order to eat. In accumulation, therefore, argues Lévi-Strauss, this succession of symbol patterns creates a logical model that asserts (or seems to assert) that, after all, life and death are *not* just the back and front of the same penny, that death is *not* the necessary consequence of life (Lévi-Strauss, 1955).

(2) Lévi-Strauss furnishes other examples. For instance, he claims, rather surprisingly, that the central problem with which the myth of Oeiipus is concerned is that of autochthonous creation. In the beginning man was created; but who precisely was created? A man plus a woman of the same kind? If so, then the perpetuation of mankind must have depended upon incest and we are all born in sin. Or was there a double creation – a man plus a woman of a different kind? In that case what are these two original kinds, and how can we justify a claim to descent from one line of ancestors rather than another?

Perhaps you wonder what all this has to do with the Oedipus myth as you know it, and I do not pretend that the Lévi-Straus example is easy to follow. FIGURE 1 may help. Lévi-Strauss assumes that the myth has a logical form corresponding to the equation: *a:b :: c:d* (*op. cit.*, pp. 55-56). The theme of incest (the overemphasis of kinship solidarity) is balanced against the themes of patricide and fratricide (the underemphasis of kinship solidarity) and this corresponds to a similar balance between the highly ambivalent sphinx and Oedipus, who, in isolation, is incomplete and crippled. The sphinx is a kind of merging of the two parent figures Jocasta and Laios. Oedipus' legitimate task is to eliminate the sphinx. He accomplishes this end by sinning doubly – incest with Jocasta and patricide against Laios. Oedipus does not actually kill the sphinx. The sphinx, which is primarily female, commits suicide, as does Jocasta. The cause of the suicide is that Oedipus answers the riddle – the answer being, in effect: "the son grows into the father and replaces him" (Lévi-Strauss, 1958 p. 238). On this analysis the myth centers around a problem of patrilineal descent: the requirement that fathers shall be perpetuated in their sons without the intervention of women, which in simple fact is

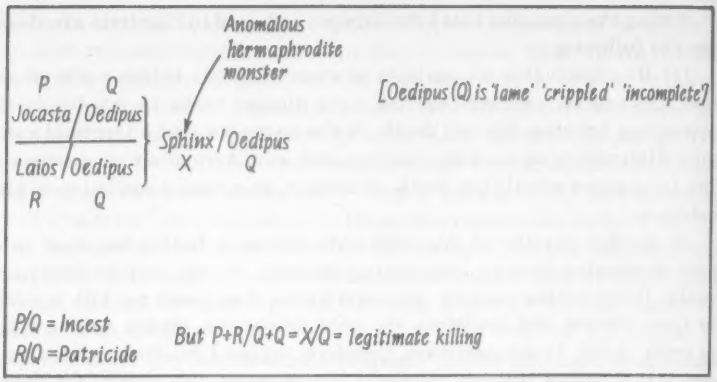

FIGURE 1.

plainly impossible. However, the impossibility is "resolved" in the myth by mediating the antithesis between male and female parents into the ambivalent person of the sphinx. Lévi-Strauss is somewhat free with his editing of the mythology, and I have been decidedly free with my editing of Lévi-Strauss. For further enlightenment I must ask you to read him in the original.

For my part I find the whole analysis extremely interesting. I feel that Lévi-Strauss has a case. We ought to investigate the hypothesis with all the means at our disposal: with or without resort to mathematical computers.

With all this in mind I decided to take another look at the story of the creation as recorded in Genesis. How well do the various theories about myth that I have mentioned stand up when put to the test against this basic myth of our own society?

The first point that struck me was that the different types of theories that I have mentioned throw the emphasis on different aspects of the story, or rather stories for, as is well known, there are two distinct creation stories in Genesis.

The symbolists favor the story concerning the Garden of Eden. Frazer and Freud and most medieval artists are in agreement that the core of the story is the matter of Eve and the serpent and the forbidden fruit. From this point of view the myth seems to provide a rather elementary example of the use of phallic symbolism. Frazer, however, made the further penetrating observation that the Tree of the Knowledge of Good and Evil, from which Eve's apple comes, is unambiguously stated to be the Tree of Death that stands opposed to another special tree, the Tree of Life. Moreover, while Adam and Eve were forbidden to eat of the Tree of Death they were not, in the first instance, forbidden to eat of the Tree of Life. (Genesis 2, v. 17).

A functionalist approach would be quite different. The story of the seven-day creation provides a mythical charter for the seven-day week. Also, in a more round about way, the creation story provides a charter for the Jewish rules of taboo as recorded in Leviticus, chapter 11.

The creation story specifies all living things as belonging to a very limited number of precisely defined categories: fowls of the air, fish, cattle, beasts, and creeping things. Similarly the plants are categorized as grass, herb-yielding seed (cereals), and fruit trees. It is further specified that the animals are intended to eat the grass while the cereals and the fruit and the meat of the animals themselves are intended for man's exclusive benefit (Genesis 1 vv. 29 and 30). As Mary Douglas has pointed out (Douglas, 1959), the creatures classified as "abominations" in Leviticus 11 are those that break out of these tidy categories: water creatures with no fins, flying creatures with 4 legs, animals and birds that eat meat or fish, and certain animals that are indiscriminate in their eating habits such as dogs and pigs.*

This functionalist treatment of the material leads to an orthodox thesis about the close association of ideas concerning taboo, sacredness, and abnormality (Radcliffe-Brown, 1952, chapter VII).

Having said all this one notices that it is only the first part of the creation story that seems to serve as a "charter" in Malinowski's sense. The second part – the Garden of Eden story that appeals so strongly to the symbolists – has no obvious implications for the functionalist. Thus neither the symbolist nor the functionalist approaches can be considered adequate. Each tells us something but neither offers an answer to the total question: What is Genesis 1 to 4 all about?

However, if we now apply a Lévi-Strauss style of analysis everything takes on a completely new shape; moreover it is a shape that recurs in both parts of the story and is repeated again in a third form in the Cain and Abel story that follows. The complex diagram (FIGURE 2) has been designed to display this structure. At every step we find the assertion of of a category opposition followed by the introduction of a "mediating" category. The seven-day creation story (upper section of the diagram) may be analysed as follows:

Genesis 1, vv. 1 to 5 (not on diagram). Light divided from darkness. Initial introduction of concept of category opposition, heaven versus earth.

Genesis 1, vv. 6 to 8 (column 1 of diagram). Fresh water above (fer-

*The thesis that tabooed animals are always "anomalous" in respect to the categories of the creation story holds good in nearly every case but not all. Thus it is not obvious to me why a camel should be an anomaly. The treatment of "creeping things" in Leviticus 11, vv. 29 to 43, is particularly illuminating in the light of the argument given below. The text starts out by attempting to distinguish as abominable certain special "anomalous creeping things," namely the weasel, the mouse, the tortoise, the ferret, the chameleon, the lizard, the snail, and the mole, but this leads logically to the conclusion that creeping things are anomalous *ab initio*, so that at v. 41 we are told that *all* creeping things without exception are abominations.

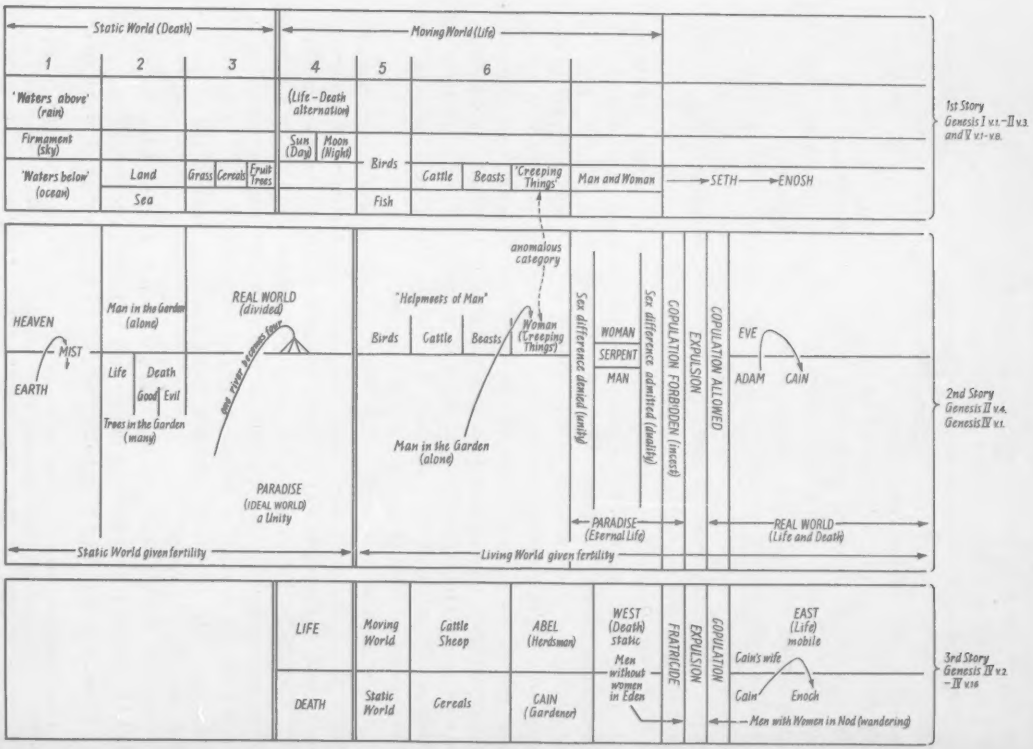
Static World (Death)
Moving World (Life)
1
2
3
4
5
6
'Waters above' (rain)
(Life – Death alternation)
Firmament (sky)
Sun (Day)
Moon (Night)
'Waters below' (ocean)
Land
Sea
Grass
Cereals
Fruit Trees
Birds
Fish
Cattle
Beasts
'Creeping Things'
Man and Woman
SETH
ENOSH
1st Story Genesis I v.1.–II v.3. and V v.1–v.8.
HEAVEN
MIST
EARTH
Man in the Garden (alone)
Life
Death
Good
Evil
Trees in the Garden (many)
REAL WORLD (divided)
ONE TREE becomes four
PARADISE (IDEAL WORLD) a Unity
Static World given fertility
anomalous category
"Helpmeets of Man"
Birds
Cattle
Beasts
Woman (Creeping Things)
Man in the Garden (alone)
Sex difference denied (unity)
WOMAN
SERPENT
MAN
Sex difference admitted (duality)
COPULATION FORBIDDEN (incest)
EXPULSION
COPULATION ALLOWED
EVE
ADAM
CAIN
PARADISE (Eternal Life)
REAL WORLD (Life and Death)
Living World given fertility
2nd Story Genesis II v.4. Genesis IV v.1.
LIFE
DEATH
Moving World
Static World
Cattle Sheep
Cereals
ABEL (Herdsman)
CAIN (Gardener)
WEST (Death) static
Men without women in Eden
FRATRICIDE
EXPULSION
COPULATION
EAST (Life) mobile
Cain's wife
Cain
Enoch
Men with Women in Nod (wandering)
3rd Story Genesis IV v.2. – II v.16

FIGURE 2.

tile rain) opposed to (salt) water below (sea). Mediated by firmament (sky).

Genesis 1, vv. 9 and 10 (column 2 of diagram). Sea opposed to dry land.

Genesis 1, vv. 11 and 12 (column 3 of diagram). Mediated by grass, herb-yielding seed, and fruit trees. These grow on dry land but need water. Very significantly, they are classed as things "whose seed is in itself" (thereby contrasted with such creatures as animals and birds, which are divided into males and females).

The creation of the world as a static (that is, dead) entity is now complete, and this whole phase of creation is opposed to the creation of moving (that is, living) things.

Genesis 1, vv. 13 to 18 (column 4 of diagram). The mobile sun and moon are placed in the firmament of column 1. Light and darkness, opposed at the beginning of the story, are now presented as alternations. By implication the life-death opposition is also an alternation.

Genesis 1, vv. 20 to 23 (column 5 of diagram). Fish and birds are living things corresponding to the category opposition of column 2 but they also mediate the oppositions between sky and land and between salt water and fresh water.

Genesis 1, vv. 24 and 25 (column 6 of diagram, left half). Cattle, beasts, and creeping things (that is, domestic animals, wild animals, and anomalous animals) correspond to the static triad of column 3 but are not allocated accordingly. Only grass is allocated to the animals, the rest is reserved for man (vv. 29 and 30).

Genesis 1, vv. 26 and 27 (Column 6 of diagram, right half). The final act of creation is the simultaneous creation of man and woman: "Male and female created he them."

The whole system of living creatures is instructed to "be fruitful and multiply," but the problems of life versus death and incest versus procreation are not faced.

The Garden of Eden story that now follows attacks from the start these very problems that have been evaded in the first version. We start again with a category opposition of heaven versus earth, but this is mediated by a fertilizing mist that is drawn up out of the dry infertile earth (Genesis 2, vv. 4 to 6). The same theme recurs throughout the story. Living Adam is formed from "the dust of the ground " (v. 7); so are the living animals (v. 19). The dry lands of the real world are fertilized by a river that comes out of the ground of Eden. In Eden (Paradise) it is a unitary river; in the real world it is divided (vv. 10 to 14). Finally fertile Eve is formed from the rib of infertile Adam (vv. 22 and 23).

The opposition of Heaven and Earth (Column 1) is followed by the opposition of Man and the Garden and, in the Garden, are trees that in-

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clude a Tree of Life and a Tree of Death (column 2: Genesis 2, vv. 8 and 9). Notice that the Tree of Death is called the "Tree of Knowledge of Good and Evil" which might also be called the "knowledge of sexual difference," or the "knowledge of logical categories." The theme is repeated: isolated unitary categories such as man alone, life alone, one river, occur only in ideal Paradise; in the real world things are multiple and divided; man needs a partner, woman; life has a partner, death.

The other living things are now created because of the loneliness of Man in Eden. The categories are cattle (domestic animals), birds, and beasts (wild animals). These are unsatisfactory as helpmeets of Man, so Eve is drawn from Adam's rib: "they are of one flesh." (columns 5 and 6: Genesis 2, vv. 18 to 24). Comparison of the two stories at this stage shows that Eve in Eden is, from a structural point of view, the same category as "the creeping things" of the first story. Creeping things were anomalous in the category opposition "cattle versus beasts;" Eve is anomalous in the category opposition "man versus animal;" and finally "the serpent" (a creeping thing) is anomalous in the category opposition "man versus woman." The parallels here with the Oedipus-Sphinx story are here extremely close, as may be seen from FIGURES 1 and 3. The

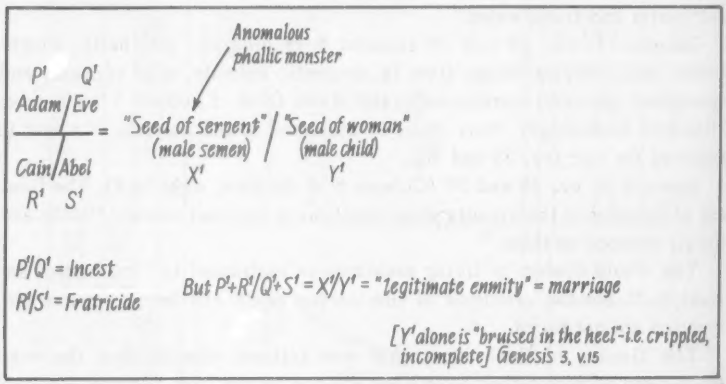

FIGURE 3.

Bible does not specify the serpent's sex. Mediaeval artists made it female, Freud might have argued for a male; the structural argument suggests hermaphrodite qualities.

Adam and Eve eat the apple and become aware of sexual difference, and death becomes inevitable (Genesis 3, vv. 3 to 8) – also of course pregnancy and life becomes possible. Significantly, Eve does not become pregnant until after they have been expelled from Paradise (Genesis 4, v. 1). The curse that is imposed on the serpent deserves especial note (Genesis 3, vv. 14 and 15). There is to be enmity between the serpent

and the woman and between "the seed of the serpent" and the "seed of the woman" – the latter being specified as male; "*he* shall bruise thy head; and thou shalt bruise *his* heel."

One is inevitably reminded of Levi-Strauss' point that autochthonous heroes are very commonly lame (Levi-Strauss, 1955). Indeed the whole formula parallels that of Oedipus. If "the seed of the serpent" be here read as "the semen of the father," while "the seed of the woman" be read as the son of the father by his impregnated wife, the curse refers to the opposition between man and woman and the hostility between father and son. It might even be taken as a "charter" for circumcision.

Finally, although very briefly, let us notice that the Cain and Abel story repeats the same story over again. The opposition between Cain the gardener and Abel the herdsman is the same opposition as that between the first three days of the creation and the last three days, the static world versus the living. Cain must eliminate his brother and substitute a wife in order that a sterile homosexual world shall become a fertile heterosexual world (Genesis 4, v. 17). Some extra elements come in here. The dead world of Eden-paradise is said to lie to the west, the living world (significantly called Nod "wandering") lies to the east (Genesis 4, v. 16); moreover, although Cain is cursed for the sin of fratricide in terms nearly identical to those imposed on Adam for the sin of incest (compare Genesis 3, vv. 17 to 19 with Genesis 4, v. 11 and 12) he is also declared a sacred person whose life is protected* (v. 15). Cain is the ancestor of "wanderers" in general – pastoralists, traveling musicians, traveling metal-workers (Genesis 4, vv. 19 to 24) – groups with special skills but not servile outcastes.

I do not claim that this kind of "structural" analysis is the one and only legitimate procedure for the interpretation of myth. It seems to me that whether any particular individual finds this kind of thing interesting or stimulating must depend on personal temperament; some may think it is too like a conjuring trick. For my part, I do find it interesting. All I have done here is to show that the component elements in some very familiar stories are in fact ordered in a pattern of which many have not been previously aware. However, the pattern *is* there; I did not invent it, I have merely demonstrated that it exists. No one will ever again be able to read the early chapters of Genesis without taking this pattern into account. Whether the analysis has any "value" for anthropologists or for anyone else I am not sure, but at least it surely throws new light on the mysterious workings of what Durkheim used to call the "collective conscience."

*Cain's peculiar status as a divinely protected person has been examined from a functionalist point of view by Schapera (1955). Here I am concerned only with the strict structural parallelism between the expulsion of Adam from Paradise followed by the pregnancy of Eve (Genesis 4, v. 1) and the expulsion of Cain from paradise followed by the pregnancy of Cain's wife (Genesis 4, vv. 16 and 17).

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CONFERENCES HELD

SECTION OF GEOLOGICAL SCIENCES AND DIVISION OF OCEANOGRAPHY AND METEOROLOGY

SOLAR VARIATIONS, CLIMATIC CHANGE AND RELATED GEOPHYSICAL PROBLEMS

Tuesday, January 24,
Wednesday, January 25,
Thursday, January 26,
Friday, January 27, and
Saturday, January 28, 1961

Conference Cochairmen:
Rhodes W. Fairbridge
Columbia University
New York 27, N. Y.

and

Charles G. Knudsen
United States Weather Bureau
New York 6, N. Y.

TUESDAY, JANUARY 24, 1961

ASTROPHYSICS: SOLAR ACTIVITY AND VARIABILITY

Session Chairman: Donald H. Menzel
Harvard University, Cambridge, Mass.

9:00 A.M. –
Greetings from the Academy – R. W. Fairbridge, Chairman, Section of Geological Sciences, The New York Academy of Sciences, New York, N. Y., and Columbia University, New York, N. Y.

"On the Nature of Solar Activity" – D. H. Menzel, Harvard College Observatory, Cambridge, Mass.

"Solar Influences on Geomagnetic and Related Phenomena" – E. H. Vestine, The Rand Corp., Santa Monica, Calif.

"Hydromagnetic Waves in the Upper Atmosphere and Solar Activity" – A. Beiser, New York University, New York, N. Y.

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"Variability of Solar Constant During the Active Life of Explorer VII" – V. E. Suomi, University of Wisconsin, Madison, Wis.

"Solar Variability in X-ray and Ultraviolet Emissions Observed by Means of Rockets" – H. Friedman, United States Naval Research Laboratory, Washington, D. C.

"Solar Radiation in the Extreme Ultraviolet Region of the Spectrum and Its Effect on the Earth's Upper Atmosphere" – W. A. Rense, University of Colorado, Boulder, Colo.

EFFECTS OF SOLAR VARIATIONS

Session Chairman: Harry Wexler
United States Weather Bureau
Washington D. C.

2:00 P.M. –

"Connections Between Solar Activity and the Planet Jupiter" – J. W. Warwick, University of Colorado, Boulder, Colo.

"The Influence of Infrared Absorptive Molecules on the Climate" – G. N. Plass, Aeronautic Research, Newport Beach, Calif.

"Temperature and Magnetic Field" – L. Egyed, Eotvos University, Budapest, Hungary.

"Sunspot Numbers and Carbon-14 Distribution" – M. Stuiver, Yale University, New Haven, Conn.

"The Pattern of Climatic Relationships" – H. C. Willett, Massachusetts Institute of Technology, Cambridge, Mass.

"Solar Cycles and the Spectrum of Time, 250 B. C. to 2000 A. D." – D. J. Schove, St. David's College, Beckenham, Kent, England.

"Climatic Change With Historical Time: Studies in Terms of Circulation Maps and Diagrams" – L. L. Lamb, Meteorological Office, Harrow, England.

"Late and Postglacial Climatic Variations in the Light of the Instrumental Meteorology of the Past 300 Years" – G. Manley, University of London, London, England.

"Some Statistical Aspects of Long-Term Fluctuations in Solar and Atmospheric Phenomena" – G. W. Brier, United States Weather Bureau, Washington, D. C.

WEDNESDAY, JANUARY 25, 1961

METEOROLOGY AND CLIMATOLOGY

Session Chairman: Bernard Haurwitz
University of Colorado, Boulder, Colo.

2:00 P.M. –

"General Circulation of Atmosphere as a Necessary Link in the Continuous Sun-Climatic Variations Chain" – B. Dzerdzeevskii, Academy of Sciences of the Union of Soviet Socialist Republics, Moscow, U. S. S. R.

"Meteorological and Geophysical Periodicities" – F. W. Ward, Jr., Atmospheric Circulation Laboratory, United States Air Force, Bedford, Mass

"Information Obtained From C^{14} and Tritium Analyses on the Circulation of the Atmosphere" – J. C. Vogel, C-14 Laboratory, Heidelberg, Germany.

"Recent Development of Climate in Scandinavia as Related to Changes of the General Circulation" – C. C. Wallen, Sweden Meteorological and Hydrological Institute, Stockholm, Sweden.

"The Radiation Balance and Recent Climatic Changes" – E. B. Kraus, Woods Hole, Mass.

"On the Relation Between Secular Changes of Climate and Sunspot Number" – J. M. Mitchell, Jr., United States Weather Bureau, Washington, D. C.

"Recent Evidence of Climate Changes and Its Implications" – I. I. Schell, Tufts University, Medford, Mass.

"Man's Activity as a Factor in Climatic Change" – H. Flohn, Deutscher Wetterdienst, Offenbach-Main, West Germany.

THURSDAY, JANUARY 26, 1961

GLACIOLOGY, OCEANOGRAPHY, AND CLIMATOLOGY

Session Chairman: Helmut Landsberg
United States Weather Bureau, Washington, D. C.

9:00 A.M. –

"Glaciers and Climate in Northern Ellesmere Island" – G. Hattersley-Smith, Department of National Defence, Ottawa, Ont., Canada.

"The Glacial History of Alaska and Its Bearing on Current Problems of Quaternary Classification and Paleoclimatic Theory" – T. N. V. Karlstrom, Coast and Geodetic Survey, United States Department of Commerce, Washington, D. C.

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"Correlation Between Isotopic Composition of Snow and Temperature of Formation" – E. Picciotto, Institut de Physique, Brussels, Belgium.

"Variations in the General Atmospheric and Hydrospheric Circulation of Few Years Period, Affected by Variations of Solar Activity" – H. P. Berlage, Royal Netherlands Meteorological Institute, De Bilt, Holland.

"Marine Transgression Sequences of the English Fenlands" – E. H. Willis, Botany School, Cambridge, England.

"Ocean Control of Quaternary Climate" – W. L. Donn and M. Ewing, Lamont Geological Observatory, Columbia University, Palisades, N. Y.

CYCLES AND PALEOCLIMATOLOGY

Session Chairman: R. F. Flint
Yale University, New Haven, Conn.

2:00 P.M. –

"Latitudinal Passage: A Principle of Solar-Terrestrial Cycle Behavior" – L. W. Wing, University of Michigan, Ann Arbor, Mich.

"Investigations of Milankovitch and the Quaternary Curve of Effective Solar Radiation" – W. Jardetsky, Manhattan College, New York, N. Y.

"Solar-Terrestrial Climatic Patterns in Varved Sediments" – R. Y. Anderson, University of New Mexico, Albuquerque, N. M.

"Upper Cretaceous and Tertiary Climatic Periodicities and Their Causes" – T. van der Hammen, Rijksuniversiteit, Leiden, Holland.

"Paleoclimatic Implications of Pleistocene Stratigraphy in the Mediterranean Area" – K. Butzer, Aachen, West Germany.

"Paleoclimatic Chronology on the European Last Glaciation" – Hugo Gross, Kunigundendamm, Bamberg, West Germany.

"Pleistocene Climates of Australia" – J. Gentilli, University of West Australia, Nedlands, Perth, West Australia.

FRIDAY, JANUARY 27, 1961

PALEOTEMPERATURES AND CYCLE EFFECTS

Session Chairman: John A. Shimer
Brooklyn College, Brooklyn, N. Y.

9:00 A.M. –

"Paleotemperatures" – F. E. Zeuner, University of London, Institute of Archaeology, London, England.

"The Effect of Internal Processes on Paleoclimates" – L. Egyed, Eotvos University, Budapest, Hungary.

"Carbon-14 Determination of Ground Water in Arid Regions" – K. O. Munnich, C-14 Laboratory, Heidelberg, West Germany.

"Correlation of Beach Terraces with Climatic Cycles of Pluvial Lake Lahontan, Nevada" – R. Shutler, Jr., Nevada State Museum, Carson City, Nev.

"Pleistocene Climatic Changes as Indicated by the Stratigraphy and Chronology of Deep-Sea Sediments of Globigerina-Ooze Facies" – C. Emiliani, Marine Laboratory, Miami, Fla.

"Pleistocene Climatic Record in Some Deep-Sea Sediment Cores" – D. B. Ericson, Lamont Geological Observatory, Columbia University, Palisades, N. Y.

"Convergence of Evidence on Climatic Change and Ice Ages" – R. W. Fairbridge, Columbia University, New York, N. Y.

PALYNOLOGY, DENDROCHRONOLOGY AND VARVE CHRONOLOGY

Session Chairman: E. S. Deevey
Yale University, New Haven, Conn.

2:00 P.M. –

"Some Aspects of Variance Spectrum Analysis Applied to Certain Natural Series" – R. A. Bryson, University of Wisconsin, Madison, Wis.

"Tree-Rings and Climatic Chronology Since 1000 B.C." – D. J. Schove, St. David's College, Kent, England.

"Climatic Change and Paleolimnology" – E. S. Deevey and G. E. Hutchinson, Yale University, New Haven, Conn.

"The Value of Late-Glacial Pollen Diagrams as Evidence of Climatic Change" – M. B. Davis, University of Michigan, Ann Arbor, Mich.

"Palynology and the Climatic Record of the Southwest" – P. B. Sears, Yale University, New Haven, Conn.

"Some Comparisons Between Climatic Changes in Northwestern North America and Southern Chile" – C. J. Heusser, American Geological Society, New York, N. Y.

"Geological and Palynological Information on the Late Quaternary Paleoclimatology of Canada" – J. Terasmae, Geological Survey, Ottawa, Ont., Canada.

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"The Quaternary Climatic Changes of Northern South America" – T. van der Hammen, Rijksuniversiteit, Leiden, Holland.

"Global Aspects of the Pleistocene Pollen Record" – D. Livingstone, Duke University, Durham, N. C.

"Botanical Record of Solar Change" – H. F. Becker, New York Botanical Garden, New York, N. Y.

7:00 P.M. –

Speaker: Alan T. Waterman
National Science Foundation, Washington, D. C.

SATURDAY, JANUARY 28, 1961

CLIMATIC CHANGE AND MAN

Session Chairman; Sheldon Judson
Princeton University, Princeton, N. J.

9:00 A.M. –

"Evidence of Climatic Fluctuations in Southwestern Prehistory" – T. L. Smiley, University of Arizona, Tucson, Ariz.

"Climatic Changes and Prehistoric Agriculture in Western America" – R. B. Woodbury, University of Arizona, Tucson, Ariz.

"Some Correlations of Climatic and Cultural Change in Eastern North American Prehistory" – J. B. Griffin, University of Michigan, Ann Arbor, Mich.

"Late Pleistocene Climatic Change in America" – A. D. Krieger, Riverside, Calif.

"Paleoclimatology and Archeology of the Middle East" – R. Solecki, Columbia University, New York, N. Y.

SECTION OF GEOLOGICAL SCIENCES

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Bartholomew Nagy
Vice-Chairman

DIVISION OF OCEANOGRAPHY AND METEOROLOGY

Charles Knudsen
Chairman

James K. McGuire
Vice-Chairman

NEW MEMBERS

Elected January 26, 1961

LIFE MEMBERSHIP

Davidson, Leon, Ph.D., Computer Program Systems. The Teleregister Corp., Stamford, Conn.

Doolittle, Stewart E., M.D. Medicine. Physician, Straub Clinic, Honolulu, Hawaii.

Eibert, John, Jr., Ph.D., Medicinal Chemistry. President of Scientific Associates, Inc., St. Louis, Mo.

Heisse, Hohn W., Jr., M.D., Otosclerosis. Instructor, University of Vermont School of Medicine, Burlington, Vt.

Isaacson, Edward K., M.D., Pediatrics. Private Practice, Arlington Heights, Ill.

Kronenber, Sanford, M.D., Physiology. Private Practice, Long Beach, Calif.

Roguski, Jan, M.D., Water and electrolyte metabolism. Head of 2nd Department, Medical Academy Poznan, Poznan, Poland.

SUSTAINING MEMBERSHIP

de la Vega, Gabriel, M.D., Biology. Psychiatrist, Elmhurst Hospital, Elmhurst, N. Y.

Durkin, John William, Jr. M.D., Obstetrics and Gynecology. Associate Director of Clinical Research, Mead Johnson & Co., Evansville, Ind.

Novic, Rudolph G., M.D., Psychiatry. Medical Director, Forest Hospital, Des Plaines, Ill.

Rosenblum, Robert R., M.D., Cardiology. Private Practice, Miami Beach, Fla.

ACTIVE MEMBERSHIP

Adams, William McChesney, Jr., V.M.D., Gynecology. Research Fellow. University of Pennsylvania, Philadelphia, Pa.

Adisman, I. Kenneth, D.D.S., Prosthodontics. Assistant Professor, New York University College of Dentistry, New York, N. Y.

Aiken, John E., M.D., Cardiac Disease. Director, Cardiopulmonary Department, Nassau Hospital, Mineola, N. Y.

Ali, Sultana Z., Ph. D., Crystallography. Senior Scientific Officer, Central Fuel Research Institute, Bihar, India.

Alivisatos, Spyridon G. A., Ph.D., Biochemistry of oligonucleotides. Head Department Biochemical Research, Mt. Sinai Medical Research Foundation & Hospital, Chicago, Ill.

Allen, Douglas F., M.D., Cardiovascular. Research Assistant, Mount Sinai Hospital, New York, N. Y.

Amar, Henri, Ph.D., Physics. Associate Professor of Physics, Temple University, Philadelphia, Pa.

Andrews, Arthur Clinton, Ph.D., Physical Chemistry. Professor, Kansas State University, Manhattan, Kans.

Andrews, Edna, Ph.D., Physiological Chemistry. Director of Laboratories, Owen Hospital, Grosse Pointe Woods, Mich.

Antlitz, Albert Michael, M.D., Cardiology. Postdoctoral Research Fellow, University Hospital, Baltimore, Md.

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Arneil, Gavin Cranston, Ph.D., Steroid Therapy. Consultant Pediatrician, Department of Child Health, University of Glasgow, Glasgow, Scotland.

Ashworth, J. N., Ph.D., Protein Chemistry. Assistant Chief, Laboratory of Blood and Blood Products, National Institutes of Health, Bethesda, Md.

Aston, John G., Ph.D., Organic and Physical Chemistry. Director, Cryogenic Laboratory, The Pennsylvania State University, University Park, Pa.

Atkinson, Ralph W., B.Sc., Engineering. Retired Consulting Engineer, Westfield, N. J.

Baddour, Raymond F., M.S. Ion Exchange. Associate Professor, Chemical Engineering. Massachusetts Institute of Technology, Cambridge, Mass.

Bailey, Catherine H., Professor of Pomology. Department of Horticulture, Rutgers, The State University, New Brunswick, N. J.

Bailey, Donald W., Ph.D., Mammalian Genetics. Chief, Genetics Research Unit, National Institutes of Health, Bethesda, Md.

Barlow, M. Althea, B.S., Science Education, Teacher, Secondary School, Baltimore, Md.

Baroni, Giancarlo, M.D., Cardiologia. Assistente Effettivo Ospedaliero, Milan, Italy.

Baruch, Herta H., M.D., Anesthesiology. Private Practice, Forest Hills, N. Y.

Baserga, Angelo, M.D., Hematology. Director, Institute of Medical Pathology, Ferrara University, Ferrara, Italy.

Bassett, Ian M., Ph.D., Chemical Physics. Researcher, IBM Watson Laboratory, New York, N. Y.

Becker, Ernest, Ph.D., Cultural Anthropology-psychiatry. Instructor, Upstate Medical Center, Syracuse, N. Y.

Bell, Alexander G., M.D. Human Genetics. Fellow, Research Institute of The Hospital for Sick Children, Toronto, Ont., Canada.

Bell, John Bernard, B.S., Physical Medicine for Rehabilitation. Private Practice, Chicago, Ill.

Beller, Harry E., M.D., Medicine. Private Practice, Miami, Fla.

Berg, Owen C., M.D., Urology. Urologist, Wichita Falls Clinic Hospital, Wichita Falls, Texas

Bergmann, Felix, Ph.D., Biochemistry. Head, Department of Pharmacology, Medical School, Jerusalem, Israel.

Berman, Joseph S., M.D., Medicine. Anesthesiologist, Newark Beth Israel Hospital, Newark, N. J.

Berman, Leonard B., M.D., Renal Diseases. Director, Renal Laboratory, Children's Hospital of The District of Columbia, Washington, D.C.

Bertossi, Felice, Ph.D., Plant Physiology. Professor of Plant Physiology, University of Bologna, Bologna, Italy.

Binder, Samuel S., M.D., Medicine. Private Practice, Chattanooga, Tenn.

Blair, Ruth, Ph.D., Human Nutrition. Professor and Head, Home Economics, University of Colorado, Boulder, Colo.

Blank, Benjamin, Ph.D., Organic and Medicinal Chemistry. Senior Chemist, Smith, Kline and French Laboratories, Philadelphia, Pa.

Block, Jerome Bernard, M.D., Medicine. Senior Assistant Surgeon, U.S. Public Health Service, Bethesda, Md.

Boren, Hollis G., M.D., Assistant Director, Professional Services for Research and Education, Veterans Administration Hospital, Houston, Texas.

Bortolami, Ruggero, Atrioventricular conduction system. Professore, Direttore dell'Istituto di Anatomia normale vete rinaria dell'Universita di Sassari, Sardegna, Italy.

Boxill, Gale C., Ph.D., Cardiovascular pharmacology and physiology. Senior Pharmacologist, Warner-Lambert Research Institute, Morris Plains, N. J.

Breitner, Carl, M.D., Psychiatry. Private Practice, Phoenix, Ariz.
Brown, Harvey E. Jr., M.D., Medicine. Private Practice, Miami, Fla.
Brughera-Jones, Antonella, M.D., Internal Medicine. Private Practice, New York, N. Y.
Bruni, Giancarlo, M.D., Endocrinology. Medical Department Staff of Vismara Terapeutici, Castenovo, Como, Italy.
Buckwalter, Frank H., M.S., Pharmaceutical Research. Director, Product Development, Bristol Laboratories Inc., Syracuse, N. Y.
Burdette, Stella Irene L., M.D., Cytological Diagnosis of Cancer, Private Practice, Balsam Lake, Wis.
Burns, Margaret Virginia, M.D., Psychiatry. Private Practice, Asheville, N. C.
Burrows, Stanley, M.D., Pathology. Chief of Laboratory Division, U.S.A.F. Hospital, Keesler, Miss.
Cahn, Theophile, M.D., Metabolism. Institut de Biologie Physico Chimique, Paris, France.
Calero, M. Carlos, M.D., Tropical Medicine. Chief, Medical Department, Raymond Clinic, Panama City, Republic of Panama.
Campbell, Benedict J. Ph. D., Biochemistry. Assistant Professor, Biochemistry, University of Missouri, Columbia, Mo.
Campbell, Charles J., M.D., Physiology of Vision. Assistant in Ophthalmology, Columbia University, New York, N. Y.
Carlson, Hjalmar E., M.D., Urology. Associate in Urology, University of Kansas School of Medicine, Kansas City, Mo.
Carrizo, V. Herminio, M.D., Sterility. Staff, St. Thomas Hospital, Panama, Republic of Panama.
Caruso, Robert A., M.D., Medicine. Private Practice, Flushing, N. Y.
Chin, Jane Heng, Ph.D., Neuropharmacology. Postdoctoral Fellow in Neuropharmacology, Stanford University, Palo Alto, Calif.
Ciampa, Virgilio A., M.D., Thoracic Surgery. Private Practice, New York, N. Y.
Citret, Coleman, M.D., Surgery. Private Practice, San Francisco, Calif.
Cohen, Alan S., M.D., Connective Tissue Disease. Assistant Professor of Medicine, Massachusetts Memorial Hospitals, Boston, Mass.
Cohen, Martin W., M.D., Immunology. Intern in Pathology, The New York Hospital, New York, N. Y.
Cohen, William, Ph.D., Biochemistry. Associate in Microbiology, Columbia University, New York, N. Y.
Coleman, Russell D., D.D.S. Bones and Teeth. Assistant Professor of Anatomy, University of California Medical Center, San Francisco, Calif.
Collins, Shirley Ann, M.D., Obstetrics-Gynecology. Assistant Director of Clinical Research, Ortho Research Foundation, Raritan, N. J.
Compton, Edgar L., M.D., Medicine. Private Practice, Las Vegas, Nev.
Coppolino, Carmela M., M.D., Pharmaceutical. Assistant Director, Hoffmann La Roche, Nutley, N. J.
Cornell, George N., M.D., General Surgery. Assistant Attending Surgeon, New York Hospital, New York, N. Y.
Crain, Stanley M., Ph. D., Nerve Cell Physiology. Head, Cell Physiology Section, Abbott Laboratories, North Chicago, Ill.
Crane, Frederick L., Ph.D., Biochemistry. Associate Professor of Biology, Purdue University, Lafayette, Ind.
Cutler, Ralph E., M.D., Metabolism and Endocrinology. Assistant Chief, Metabolic Service, Wadsworth General Hospital, Los Angeles, Calif.
Dahler, John S., Ph.D., Statistical Mechanics. Assistant Professor, Department of Chemical Engineering, University of Minnesota, Minneapolis, Minn.
Dalton, Philip Benjamin, M.A., Acetylene Chemicals. Manager, Antara Chemicals

Division of General Aniline, Franklin Square, L. I., N. Y.

Damaskus, Charles W., B.A., Cancer Chemotherapy. Senior Research Scientist, Pharmaceutical Co., Kankakee, Ill.

Dansky, Leonard M., Ph.D., Nutrition-Biochemistry. Director of Research, Samuel Lipman Sons, Augusta, Me.

Danti, Alfred, Ph.D., Molecular Structure. Assistant Director, MCA Research Project, Carnegie Institute of Technology, Pittsburgh, Pa.

Darter, Robert W., M.D., Medicine. Epidemic Intelligence Officer, U.S. Public Health Service, Phoenix, Ariz.

Davies, Merton Edward, A.B., Photography. Liaison Engineer, Rand Corporation, Santa Monica, Calif.

Davis, Charles E., M.D., Obstetrics and Gynecology. United States Air Force, Ellsworth, So. Dak.

Davis, Harry P., B.S., Engineering Management. Plant Manager, The Clorox Company, Cleveland, Ohio.

De Caro, Luigi, M.D., Physiology. Dean of the University of Pavia, Pavia, Italy.

de Goldfiem, Jean, M.D., Nutritional Physiology. Rector Magnifico, International University Moctezuma, Paris, France.

De Marco, Michael, M.D., Medicine. Private Practice, New York, N. Y.

Denser, Clarence Hugh, M.D., Medicine. Private Practice, Des Moines, Iowa.

Dessi, Pietro, Pharmacology. Assistente e docente nell'Istituto di Farmacologia dell'Universita di Bologna, Bologna, Italy.

Dinnerstein, Dorothy, Ph.D., Psychology, Assistant Professor, Psychology, Rutgers, the State University, Newark, N. J.

Dodson, Raymond M., Ph.D., Steroids. Professor of Chemistry, University of Minnesota, Minneapolis, Minn.

Donnet, Vincent, Physiology. Professor, Experimental Medicine, Marseilles, France.

Donovan, John C., M.D., Obstetrics and Gynecology. Assistant Professor of Obstetrics and Gynecology, University of Rochester, Rochester, N. Y.

Driscoll, John J., M.D., Medicine. Obstetrician and Gynecologist, Elmhurst Clinic, Elmhurst, Ill.

Drungis, Anne M., B.A., Pharmacology (Toxicology). Scientist, Squibb Institute for Medical Research, New Brunswick, N. J.

Ebert, William R., Ph.D., Research Administration. Scientific Director, Columbus Pharmacal Company, Columbus, Ohio.

Eckelmann, Walter R., Ph.D., Tulsa, Okla.

Eckenfelder, W. Wesley, Jr., MCE, Sanitary Engineering. Associate Professor, Civil Engineering, Manhattan College, New York, N. Y.

Edgerton, William H., Ph.D., Ethical Pharmaceuticals. Head of Patent Section, Smith, Kline & French Laboratories, Philadelphia, Pa.

Egeland, A. W., High-latitude radio wave propagation. Kiruna Geophysical Observatory, Kiruna, Sweden.

Eich, Stephen, Ph.D., Biochemistry. Research Biochemist, G. D. Searle and Co., Chicago, Ill.

Eichhorn, John Harris, Ph.D., Endocrinology. Staff Scientist, Worcester Foundation, Shrewsbury, Mass.

Eikrem, Lynwood Olaf, SM., Electro-optical Instrumentation. Product Development Manager, David W. Mann Company, Lincoln, Mass.

Ejrup, B., M.D., Medicine. Karolinska Sjukhuset, Stockholm, Sweden.

Elia, Joseph Charles, M.D., Chemotherapy. Private Practice, Reno, Nev.

Elsea, John R., Ph.D., Toxicology. Director of Toxicology, Hill Top Research Institute, Inc., Miamiville, Ohio.

Enzer, Norbert, M.D., Pathology and Medicine. Director of Laboratories, Mount

Sinai Hospital, Milwaukee, Wis.

Evans, Robley D., Ph.D., Nuclear physics and radiobiology. Professor of Physics, Massachusetts Institute of Technology, Cambridge, Mass.

Falconi, Gianni, M.D., Endocrinology. Researcher, Vister, Casatenovo, Como, Italy.

Farfor, Keith Mrs., B. Sc., Endocrinology. Research Assistant, Alfred Hospital, Melbourne, Australia.

Ferenzi, George W., M.D., Internal Medicine. Associate attending physician, Mercy Hospital, Chicago, Ill.

Ferreira, Sidney, M.D., Medicine. Private Practice, Kingston, Jamaica, British West Indies.

Ferrer, Olga M., M.D., Ophthalmology. Associate Professor, University of Miami, School of Medicine, Miami, Fla.

Fiore-Donati, Luciano, M.D., Pathology and Cancer Research. Assistant in Pathology, Universita Di Bari, Bari, Italy.

Fitzmaurice, Mary Anne, B.S., Viral Ethiology of Cancer. Research Aide, Sloan-Kettering Institute for Cancer Research, New York, N. Y.

Forman, Charles, M.D., Medicine. Private Practice, New Rochelle, N. Y.

Frangatos, Gerassimos, Ph.D., Pharmaceutical Research. Senior Research Chemist, F. W. Horner Ltd., Montreal, Quebec, Canada.

Frankel, Victor H., M.D., Orthopaedic Surgery. Research Associate, The Hospital for Joint Diseases, New York, N. Y.

Freed, Isidore, M.D., Internal Medicine. Private Practice, New York, N. Y.

Freedman, Mark A., M.D., Biological and Medical Sciences. Hospital Administrator, Beth Israel Hospital, New York, N. Y.

Frey, Martha L., Medical Library. Assistant Librarian, Montefiore Hospital Medical Library, New York, N. Y.

Friedman, Emanuel A., M.D., Obstetrics and Gynecology. Assistant Professor, Columbia University, New York, N. Y.

Friou, George J., M.D., Immunology. Associate Professor, University of Oklahoma Medical Center, Oklahoma City, Okla.

Gabel, Lloyd P., M.S., Pharmacology. Associate Scientist, Warner-Lambert Research Institute, Morris Plains, N. J.

Gabriel, Richard Francis, Ph.D., Mathematics. Associate Professor, Mathematics, Rutgers, the State University, New Brunswick, N. J.

Gabrio, Beverly Wescott, Ph.D., Erythrocyte Metabolism. Director of Research, King County Blood Bank, Seattle, Wash.

Gadebusch, Hans H., M.S., Immunochemistry. Coordinator of Research, Veterans Administration Hospital, Ann Arbor, Mich.

Galambos, John T., M.D., Sulfomucopolysaccharides. Assistant Professor of Medicine, Emory University School of Medicine, Atlanta, Ga.

Geller, Jac S., M.D., Surgery. Senior Clinical Instructor in Surgery, Western Reserve University Medical School, Cleveland, Ohio.

Georgian, Vlasios, Ph.D., Organic Chemistry. Professor, Tufts University, Medford, Mass.

Gilson, Saul B., M.D., Medicine. Private Practice, New York, N. Y.

Goetz, Robert H., M.D., Cardiovascular. Director of Physical Research, Einstein College of Medicine, Bronx, N. Y.

Goldstein, Lester, Ph.D., Cell Biology. Associate Professor, Biology, University of Pennsylvania, Philadelphia, Pa.

Goodson, Louis H., Ph.D., Medicinal and Biochemistry. Head, Biochemistry Section, Midwest Research Institute, Kansas City, Mo.

Gourevitch, Alexander, Ph.D., Antibiotic Research. Assistant Director, Bristol Laboratories, Syracuse, N. Y.

Gravel, Joffre André, M.D., Medicine. Surgeon, Laval Hospital, Quebec, Canada.

Gregory, Charles, M.B., Research Associate. Department of Psychiatry, University of Toronto, Toronto, Canada.

Griboff, Solomon L., M.D., Internal Medicine. Staff Physician in Medicine, Long Island Jewish Hospital, New Hyde Park, N. Y.

Griffo, Zora E. Jasincuk, Ph.D., Cardiovascular Physiology. Assistant in Anesthesiology, Washington University School of Medicine, St. Louis, Mo.

Grigg, E. R. N., M.D., Clinical Radiology. Attending Radiologist, Cook County Hospital, Chicago, Ill.

Gross, Benjamin H., Ph.D., Organic Chemistry. Research Chemist, The Chattanooga Medicine Company, Chattanooga, Tenn.

Gross, Ralph H., Reticuloendothelial cell function. Retired poultry farmer, Fort Lauderdale, Fla.

Gussen, John, M.D., Psychiatry. Director, Department of Psychiatry, Cedars of Lebanon Hospital, Los Angeles, Calif.

Gutstein, William H., M.D., Biophsics and Experimental Pathology. Assistant Professor of Pathology, New York University School of Medicine, New York, N. Y.

Haessig, Alfred, M.D., Immunopathology. Director, Central Laboratory Blood Transfusion Service of the Swiss Red Cross, Berne, Switzerland.

Hair, Walter W., M.D., Endocrinology. Department of Internal Medicine, Irwin Army Hospital, Fort Riley, Kans.

Harsch, Mary, Ph.D., Cellular Physiology. Research Associate, Rutgers, the State University, New Brunswick, N. J.

Healey, Raymond P., M.S., Physiology. Science Teacher, Smithtown High School, Smithtown, L. I., N. Y.

Henley, Felix T., M.D., Radiology. Assistant Professor, Radiology, University Hospital, University of Alabama Medical Center, Birmingham, Ala.

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